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Ground-Water Flow Modeling
Study of the Love Canal Area, New York

GCA Corp., Bedford, MA

Prepared for

Environmental Monitoring Systems Lab.
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16. ABSTRACT

As part of the overall Love Canal monitoring effort an assessment of the ground water hydrology of the Love Canal area, New York was performed. As part of this assessment, ground-water flow models were used to aid in well siting, data analysis and reduction, and prediction of ground water movement. This report describes the model development, use of model in site selection, and use of model to make predictions concerning spread of contamination. Major conclusions of the report are: (1) Primary water bearing zones are located in the upper zones of the Lockport Dolomite; (2) Assuming a downward gradient through confining beds, and beds were not breached or fractured, it would take a pollutant hundreds to thousands of years to reach the Dolomite; (3) The French drain system will cause most outward ground water flow to reverse direction back toward the drain.

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FINAL REPORT ON
GROUND-WATER FLOW MODELING STUDY
OF THE LOVE CANAL AREA, NEW YORK

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SECTION 1.0 CONCLUSIONS AND RECOMMENDATIONS

The conclusions and recommendations presented in this report are based on geohydraulic analysis of the Love Canal site. They do not include any information resulting from chemical analysis of the water samples taken from the wells drilled during this project.

1.1 CONCLUSIONS

The following conclusions can be made based on the analysis of the aquifer testing:

(1) The 22 hour discharge test in the Lockport Dolomite provided a field average transmissivity of 0.015 ft^2/s and storage coefficient of 0.00015. These values are consistent with other values determined for the Lockport Dolomite in the Niagara vicinity.

(2) Because many of the observation wells were completed only a few feet into the dolomite, and because they responded quickly to the pumping from a much deeper well, the upper permeable zones of the dolomite appear to have significant vertical permeability.

(3) The Lockport Dolomite is heterogeneous but less so than would normally be anticipated for carbonate aquifers.

(4) The packer test results for the dolomite were inconclusive. Consequently, the regional observations of Johnston (1964) regarding the variation of hydraulic conductivity with depth are still assumed applicable to the site. Examination of the core description also supports Johnston's contention that the primary water bearing zones are located in the upper zones of the Lockport Dolomite.

(5) The slug test in the overburden wells provided an estimate of the hydraulic conductivity of the lacustrine sediments and till. Both values are on the order of 10^{-9} ft/s and indicate relatively impermeable material.

(6) The shallow material tested at the slug test site was also relatively impermeable (on the order of 10^{-9} ft/s).

However, this unit was quite clayey. Because the shallow silty-sandy units are highly variable, this one estimate is probably not representative of the shallow system at the site.

(7) No estimates of storage properties for the overburden wells could be determined from the slug tests.

Based on modeling results, conclusions regarding the Lockport Dolomite are:

(1) Steady-state flow in the dolomite on a regional scale is maintained by recharge through confining beds from the topographic high near the escarpment. Discharge generally occurs along the Niagara Escarpment, toward the covered conduits, and along parts of the upper Niagara River. Locally, in the Love Canal area, the gradient is south and southwesterly toward the upper Niagara River.

(2) In the Love Canal area the vertical gradient through the confining bed is very low, with flow rates on the order of 10^{-3} in/yr. The direction of flow depends on the local gradient between the shallow system and the dolomite. It could be in either direction, and as the heads fluctuate seasonally, the gradient may reverse.

(3) The Love Canal site is far enough from the covered conduits of the pump-storage project that this boundary has little effect on heads at Love Canal.

(4) Computed hydraulic heads in the Love Canal area were relatively insensitive to changes in transmissivity of the order 50% and less.

(5) Computed hydraulic heads in the Love Canal area were also relatively insensitive to changes of 50% or less in the confining bed hydraulic conductivity.

(6) Steady-state heads in the Love Canal area were most sensitive to changes in the value used to represent constant head at the upper Niagara River.

(7) If solute were to enter the Lockport Dolomite at the south end of Love Canal, and if there were no adsorption, the mean travel time to the upper Niagara River for the solute would be 1000 days. This is dependent on assumptions concerning the flow properties.

(8) Assuming a downward gradient through the confining bed, and that the confining bed was not breached and does not contain fracture zones, it would take a nonadsorbing solute on the order of hundreds to thousands of years to reach the dolomite. If adsorption occurs, travel times will be even longer.

(9) If solute is found in the dolomite and is related to waste from the Love Canal, given the long travel times calculated for the confining bed, the most likely explanation would be that the confining layer had been breached by excavation.

(10) If the confining bed were breached by excavation, downward flow could produce a ground-water high in the dolomite. Since the hydraulic heads in the two systems are nearly equal, however, it is not possible, based on hydrologic evidence alone, to determine whether the confining bed was breached.

(11) The gradient in the dolomite toward the river can be reversed by placing intercept wells near the south end of Love Canal. This can be accomplished with a total pumpage as low as 6 gal/min or 8640 gal/day.

Modeling the shallow system provides the following conclusions:

(1) Over the past 30 years, ground water could have migrated about 35 ft from the canal in the less permeable material (K of 3×10^{-6} ft/s and effective porosity of 10%) For higher permeability material (K of 3×10^{-4} ft/s and effective porosity of 15%), over the past 30 years ground water could have migrated up to 1900 ft from the canal. Considering the discontinuous and heterogeneous nature of the shallow system, the actual distance of ground water migration will lie between these extremes with a much lower probability of the greater distance.

(2) Based on history matching of the French drain flow data, the shallow system may be characterized as having averaged hydrologic properties with a bulk hydraulic conductivity of 3×10^{-6} to 3×10^{-7} ft/s (10^{-4} - 10^{-5} cm/s) and effective porosity of 10-15%.

(3) Although the clay sediments in the shallow system are considered to have a low permeability, much smaller than the silty sands, fissured zones which occur in the clays can impart a higher permeability closer to that of the silty sands.

(4) The French drain is an effective remedial action to prevent further migration of contaminants in the shallow system away from the drain. No contaminated ground water in the less permeable material (K of 3×10^{-6} ft/s) would have traveled further than the drain in the past 30 years where the drain is at least 35 feet from the canal.

(5) The French drain will cause most ground water (which has migrated through high permeability pathways) beyond the drain in the past 30 years to reverse flow back to the drain.

(6) Since ground-water movement in the general shallow system is slow, migration of contaminants from the canal to nearby residences must have occurred through zones of higher permeability such as swales, sand lenses or utility trench backfill, or occurred through overland flow across ground surface or from burial of waste much closer to residences than previously suspected.

(7) Based on modeling results and knowledge of the shallow system, there is a low probability of subsurface migration of contaminants from the canal beyond the first circle of residences except in isolated high permeability zones. If contamination is found outside the first circle of homes, the contamination may be due to other than solely subsurface migration.

(8) Availability of data collected on a continuing basis of one to three years would allow refinement of predictions and conclusions. With the additional data then available, more detailed ground-water flow and solute transport models would be applicable.

4

1.2 RECOMMENDATIONS

(1) Water-level data on wells drilled during this study should be monitored on a continuing basis. A necessary practice in ground-water studies is to obtain historical data to see how the system behaves with time. Comparisons of model results with historical data then provide a level of credibility in predictions. A general guideline used in the petroleum industry for predictive simulations is: predict with confidence for one half the period of the historical match. In the study at Love Canal, essentially no historical data on the scale of the problem was available. The data collected basically represented a point in time. Monitoring data to be collected can be used to verify and improve the findings of this study.

(2) A remaining question from the current study is how well the river is connected to the Lockport Dolomite and shallow system. We recommend that the Niagara River be monitored along with wells near the river. Variations in the river stage should be reflected in the water levels in the dolomite and shallow system. Using this information, calculations can be made to determine the connectivity.

(3) Monitoring of wells in the shallow system nearest the drain field should be performed to verify the effectiveness of the drains.

(4) If significant contamination is found in the shallow system beyond the current system of drains, transport modeling may be used to estimate natural attenuation. If natural dissipation is not adequate, extension of the current drainage system may be necessary.

(5) If significant contamination is found in the dolomite, it may be necessary to drill additional wells to the south and west of the canal, in order to define the extent of the contamination.

(6) Modeling techniques, in conjunction with field activities, provided valuable insight into the hydraulic behavior of the ground-water system at the Love Canal site. It is recommended that techniques such as those used in this study be used in subsequent studies of hazardous waste sites.

(7) The most effective use of ground-water models is an iterative process, where modeling and field activities proceed simultaneously with continuous feedback. Because of the short time frame (three months) within which the work had to be completed, this continuous feedback process was limited. In future studies, we recommend that more time be allowed for information transfer. This will also allow sufficient time to document all steps and thereby enhance quality assurance.

(8) Because of the short time frame of the study, work in different areas had to proceed without any ordering of the tasks. For example, wells had to be drilled without knowing chemical and hydrological results from previous wells. This probably resulted in wells being drilled that were not necessary, therefore, needlessly increasing the cost of the study. In future studies, we recommend that the following sequence of events be followed: (i) review available data concerning the site, (ii) drill a few wells to obtain necessary additional data, and perform the necessary geophysical and geochemical surveys, (iii) analyze data, and (iv) drill additional wells and perform additional surveys, if necessary.

SECTION 2.0 INTRODUCTION

2.1 GENERAL

The Environmental Protection Agency through its prime contractor, GCA, identified a need to assess the ground-water hydrology of the Love Canal Area, New York. As part of this assessment, ground-water flow models were used to aid in well siting, data analysis and reduction, and to attempt prediction of ground-water movement. The modeling portion of the assessment was subcontracted to GeoTrans, Inc. The modeling effort was started on 20 August 1980 and completed 1 December 1980. This report describes the work provided by GeoTrans to GCA. The following tasks were outlined in the Statement of Work provided by the GCA Corporation:

(1) Develop a model (or apply an existing model) capable of predicting the movement of ground water in each aquifer. The model will consider the alterations to ground-water flow that might result from:

- areal hydrologic changes
- existing and potential pollution control methods at Love Canal
- swales, pipelines, agricultural drainage pipes, underground utility installations, and other possible avenues of ground-water movement.

(2) Use the model to assist in the selection of drilling sites.

(3) Use the calibrated model to make predictions concerning the spread of contamination over the next five years. Predictions will be limited to the movement of conservative contaminants in the

ground water under varying conditions of discharge and recharge. Predictions will specifically consider a range of precipitation conditions typical of historical observations in the area.

2.2 REVIEW OF BASIC CONCEPTS

In this section a simplified overview of ground-water hydrology is presented. Common terminology is discussed for the benefit of those unfamiliar with ground water. For more details, a text on ground-water hydrology should be consulted, such as Freeze and Cherry (1979).

Ground water refers to the water below the land surface that fills pores or cracks in soil and rock. This pore space is generally measured as a volumetric percentage of the total volume and is labeled porosity (dimensionless). For example, water may be added to a bucket of sand until the sand is saturated (filled with water). If the volume of water added is 20% of the volume of the bucket, then the porosity of the unconsolidated sand is 20% or 0.2, regardless of whether the sand is saturated or unsaturated. Under certain conditions, such as dead-end pores or large surface tension effects, some of the water in the pores does not move. To account for this immobile water the term effective porosity is used to indicate the ratio of the void space through which flow can occur to the total volume.

An analogy may be made between surface water and ground water. Just as the water level of a river can be measured and partially determines the flow of the river, water levels in ground water can also be measured and used to help determine flow. The water level is generally measured relative to a datum of mean sea level elevation and is called hydraulic head (length). Unlike the river, to obtain this measurement for ground water requires that wells be drilled. The three-dimensional surface that hydraulic head measurements produce is called the potentiometric surface. Just as water in a river flows downhill, that is, from a higher water level to a lower water level, ground water also flows from higher to lower hydraulic head.

Unlike river water, however, flowing ground water has to overcome the resistance of the rocks or soil. An indication of this resistance or a measure of how well the pores are connected is known as hydraulic conductivity (length per unit time). Hydraulic conductivity is composed of two parts, one that is a property of the medium and the other that is a property of the fluid. The part that is a property of the medium is called permeability (length squared).

Whereas the direction of ground-water flow is determined by the hydraulic head gradient (changes in head with distance), ground-water flow rates are determined by both hydraulic conductivity and the hydraulic head gradient. Wells are again required, along with field tests, to determine hydraulic conductivity. A common type of field test is a pumping test. Pumping tests, as the name implies, are tests where one well is pumped and water-level declines in nearby observation wells or in the pumping well itself are measured. Using the pumping as the forcing function and the water-level measurements as the response, hydraulic conductivity may be 'backed out'. The parameters, porosity, hydraulic gradient and hydraulic conductivity are especially important in ground-water contamination problems, since they determine the convective flow rates of the contaminant, and in large part, determine travel times.

The term aquifer is used to indicate a layer of rock and/or unconsolidated material that can transport reasonable amounts of water, that is, the layer has a significant hydraulic conductivity. Aquifers are generally divided into confined or unconfined conditions. A confined aquifer is one that is overlain by a low-permeable layer; an unconfined aquifer is one that is also referred to as a water-table aquifer, where the water table is simply the potentiometric surface for that aquifer. Often an aquifer may be considered fairly uniform with depth and the corresponding properties are averaged over the aquifer thickness. A result of this averaging is the product of hydraulic conductivity and the aquifer thickness, which is called transmissivity (length squared per unit time). It represents the ability of the entire thickness of the aquifer to transmit water.

In addition to transmitting water, aquifers are reservoirs that also store water. The storage properties of aquifers (over the entire thickness) are described by a term labeled storage coefficient (dimensionless), which varies widely depending on whether the aquifer is confined or unconfined. This parameter is also determined from pumping tests and only enters into an analysis when groundwater flow is transient, as opposed to steady-state flow, when hydraulic head is invariant with time. Steady state also implies that there is no change in storage, that is, recharge, such as infiltration from rainfall, equals discharge, such as seepage to a river.

The flow of water through the rock or unconsolidated material is generally assumed to behave similarly to flow in porous media, which may be described mathematically by a partial differential equation with appropriate boundary and initial conditions. The equation parameters are source/sink terms, transmissivity multiplying the space derivatives, and storage coefficient multiplying the time derivative, where the dependent variable is hydraulic head. For steady-state flow the time derivative is zero and the equation parameters reduce to source/sink terms, such as recharge, and transmissivity. Boundary conditions are generally of two types: specified head and specified flux. An example of a specified head boundary is the intersection of a water-table aquifer with a large river or lake where the water level is relatively constant. A special case of a specified flux boundary is that where the flux is zero. This is used to represent the contact of an aquifer with a low-permeability unit such as crystalline rock. Given boundary conditions and equation parameters, the partial differential equation may be solved to obtain the hydraulic head distribution. This distribution may be used to compute ground-water velocities. For contamination problems, these velocities are used in an additional partial differential equation that describes the transport of solutes. A solution to this equation provides concentration distributions.

2.3 TECHNICAL APPROACH

In very general terms, the purpose of this work was to apply ground-water flow models to help interpret and predict the ground-water flow and conservative contaminate behavior at Love Canal. The assumption of conservative contaminate behavior ignores attenuation effects and therefore, in general, represents a worst-case assumption. Since hydrodynamic dispersion is neglected, however, arrival times may be underestimated. A ground-water flow model attempts to represent reality by explaining certain aspects of the actual aquifer. Throughout the study, models of varying complexity were used - conceptual models, simple algebraic formulas, complicated mathematical solutions, and numerical models requiring computer solutions. However, no matter how sophisticated the model, it is always less complex than the real system it represents.

Although a model can never be as complex as the system it represents, it can be more sophisticated than is necessary or than the supporting field data warrant. The results of a model are no more meaningful than the quality the field data permits. For example, a ground-water flow model used to describe flow in three-dimensions would be inappropriately applied for prediction to an aquifer with only a few observed heads.

These two observations, (1) that models can never be as complex as reality and (2) models should not be more sophisticated than necessary, suggest some general modeling guidelines:

(1) Document the major assumptions of the model. Whether this model is a simple formula or a complex numerical model, major assumptions should be clearly stated.

(2) Contrast model assumptions with actual field conditions. Explain the significance of any discrepancy between the two.

(3) Use all available data in interpreting model results; this includes qualitative as well as quantitative data.

(4) Use the simplest model consistent with model objectives and data availability.

(5) Use models for purposes consistent with data. For systems with little available data, models can be applied to help with system conceptualization. For systems with a good data base, models can be used for predictions.

(6) Document the uncertainty in model predictions. This can be done by using sensitivity analysis or by statistical techniques.

During this study these guidelines were followed. In order to select models consistent with data availability and project needs, a thorough literature search was undertaken to obtain existing data. To the extent possible (limited by very tight schedules) data collection activities and modeling needs were coordinated. As data became available they were incorporated into decisions on model selection and problem specification.

Part of the data that was extremely difficult to explain by ground-water flow patterns alone was the pH data observed in wells. Many of the well water samples had high pH values. A possible explanation is included in Appendix A, a memorandum from Dr. F. J. Pearson, a quality assurance reviewer on this project. His analysis suggested that the high pH observation may be due to cement used in well construction. This led to the collection of additional chemical data needed to evaluate the source of high ph conditions. Field measurements later verified this explanation correct when extensive purging of the high-pH wells resulted in pH measurements that went to neutral. This is an example of feedback that should occur among modeling and data collection activities.

In preparation of this final report the modeling guidelines were also considered. We have tried to emphasize model assumptions, corresponding field conditions, and data limitations for each model application. In most sections this information is summarized in tabular form as well as in the text.

SECTION 3.0 LITERATURE REVIEW

3.1 GENERAL

During the early part of this study a review of the available literature on the Love Canal site was performed. Pertinent data from this review on the ground-water system at Love Canal are synthesized in this section. This information was used to provide guidance in designing the aquifer tests, as well as in preparing preliminary ground-water models.

The Love Canal site is located on the east side of Niagara Falls, New York (see Figure 3.1). The landfill at Love Canal was operated for a 25 to 30 year period. In 1953, the landfill was covered with soil, apportioned and sold to municipal and private owners. There were no definitive records of its dimensions, of the wastes disposed in the canal, of the waste contributors, nor of the waste locations (Fred C. Hart Associates, Inc., 1978). The canal occupied a surface area of approximately 16 acres with the south end ¼ mile from the Niagara River near Cayuga Island. It varies from about 10 to 35 feet in depth with the original soil cover varying from 0 to 6 feet in thickness (Leonard, et al., 1977).

Figure 3.2 shows the typical strata at the Love Canal site reported by Conestoga-Rovers and Associates (1979).

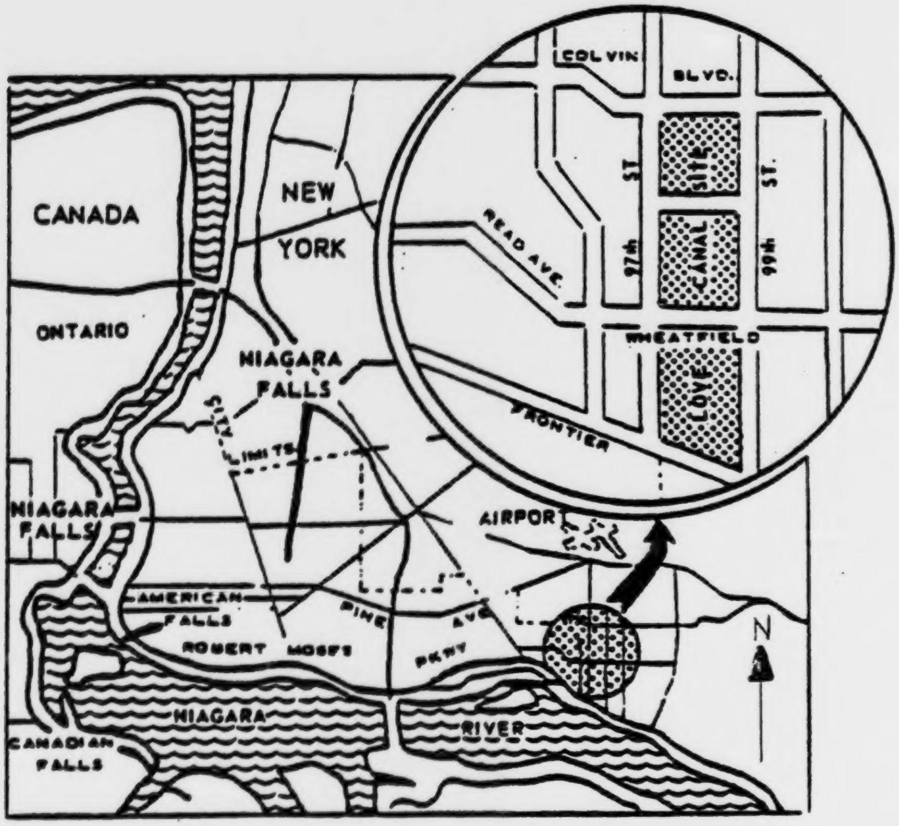


Figure 3.1 The location of the Love Canal Site in Niagara Falls, New York (from Clement Associates, 1980)

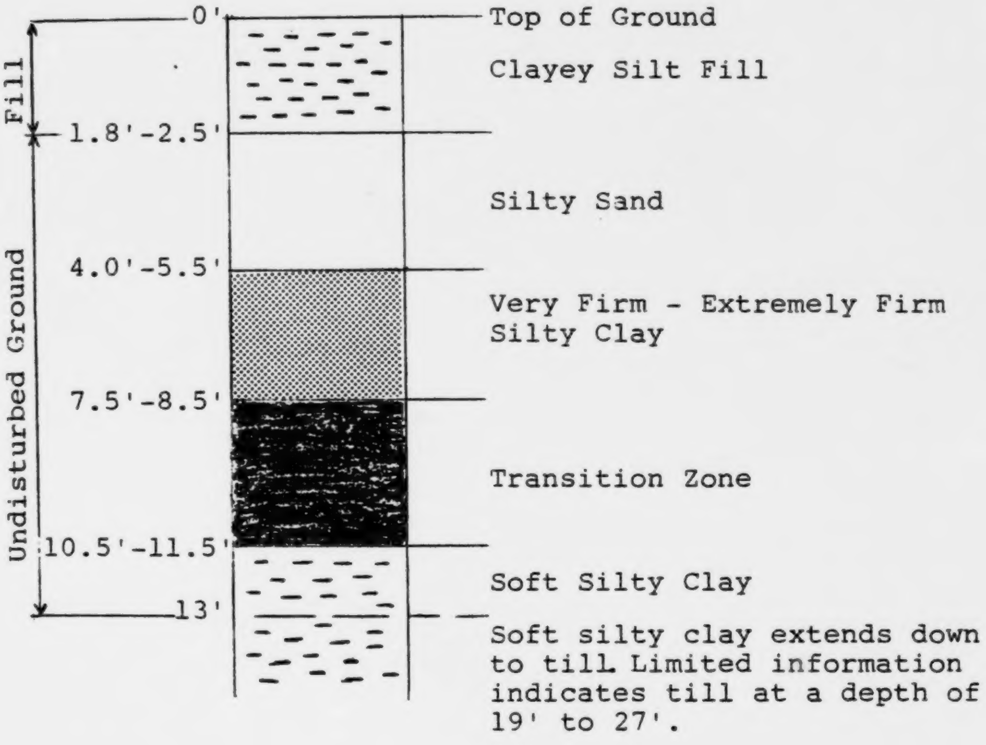

0'
Top of Ground
Clayey Silt Fill
Fill
1.8'-2.5'
Silty Sand
4.0'-5.5'
Very Firm - Extremely Firm Silty Clay
7.5'-8.5'
Transition Zone
Undisturbed Ground
10.5'-11.5'
Soft Silty Clay
13'
Soft silty clay extends down to till. Limited information indicates till at a depth of 19' to 27'.

Figure 3.2 Typical strata in Love Canal landfill area (after Conestoga-Rovers and Associates, 1979).

Not shown but below the soil is a glacial till. This is underlain by bedrock which consists of the Lockport Dolomite. In very general terms, the ground-water hydrology includes: (1) a shallow system that is seasonally saturated and consists of the silt fill and silty sand, and is underlain by (2) a bed of confining material composed of clay and till that overlies (3) the Lockport Dolomite, which is underlain by the relatively impermeable (4) Rochester Shale.

3.2 LOCKPORT DOLOMITE

The following discussion is based on information from Johnston (1964). As stated, the Lockport Dolomite is overlain by leaky confining beds and underlain by the relatively impermeable Rochester Shale. It is fairly continuous in the Niagara Falls area and is considered an aquifer with both artesian and water-table conditions. It is a fractured system, with most of the permeability occurring in the top 10 to 15 feet. The dolomite is probably bounded hydrogeologically in the Niagara Falls area to the south by the upper Niagara River (see Plate 1). It is bounded toward the west by the lower Niagara River and associated channel. The dolomite thins northward where it is bounded by the Niagara escarpment.

Under natural conditions, recharge occurred at the contact with the upper Niagara River near the falls and at an elevation high just south of the Niagara escarpment. Discharge occurred as seepage faces or springs at the lower Niagara River, along the Niagara escarpment, and possibly along parts of the upper Niagara River away from the falls. Annual precipitation is approximately 30 inches.

A generalized potentiometric map for the Lockport Dolomite is shown in Plate 1. This was constructed using data in Johnston (1964). The contours are highly idealized because the data were either (1) absent, (2) represented several layers within the dolomite, or (3) collected over a two year time span during 1961-1962.

Even with this uncertainty, much worthwhile information can be gained from this potentiometric map. As noted, in many locations, the highs correspond to topographic highs. This is especially obvious near the Niagara escarpment where a recharge area produces flow toward the north, discharging as springs at the escarpment, and toward the south and the Love Canal site.

The natural flow conditions have been disrupted by discharge from wells and by a pumped-storage reservoir (including conduits and canals). According to Johnston (1964),

> "By far the greatest use of ground water in the Niagara Falls area is by industries. Approximately 8 mgd of ground water (80 percent of that used in the area) is used for industrial purposes, mainly for cooling and processing by chemical industries in the city of Niagara Falls. This water is obtained from a few wells of exceptionally high yield in the Lockport Dolomite."

These are located in a narrow band that intercepts the upper Niagara River about two miles east of the falls. The pumped-storage reservoir occupies about 3 square miles northwest of the city of Niagara Falls. An average operating reservoir water level of 645 feet has caused significant increases in nearby water levels in the upper part of the dolomite, and locally artesian flow was caused to occur. The effect of the pumped-storage reservoir is to produce a ground-water high, whereas the conduits have produced a discharge area. These have caused complex flow patterns; however, near the Love Canal site the gradient is relatively uniform with flow being toward the upper Niagara River, that is, toward the south and southwest.

As shown in Plate 1, near Love Canal, the water level is greater than 560 feet above mean sea level. Since Johnston (1964) had little data in this area, the potentiometric surface here is extrapolated. Since the land elevation is approximately 570 feet, depth to water in a well completed in the dolomite should be about 10 feet. Leonard, et al. (1977) indicated water levels in the Love Canal area that ranged from 537 to 549 feet above mean sea level. These values are lower than those reported by Johnston (1964) and seem inconsistent.

Also indicated on Plate 1 are the locations of the major pumping center and well HY1. Well HY1 is Johnston's well 306-902-1. A hydrograph for this well is shown in Figure 3.3

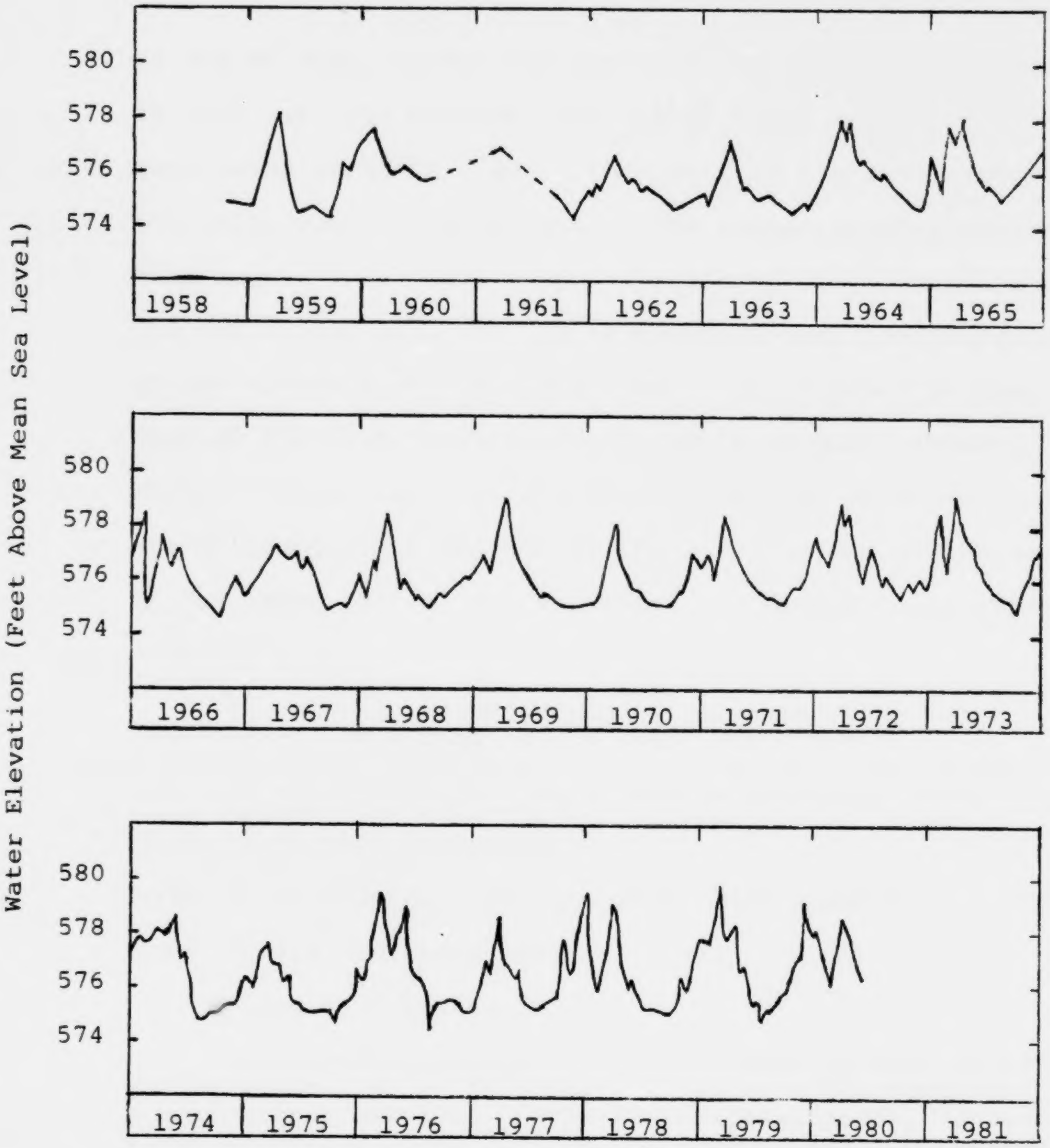


Figure 3.3 Hydrograph of well HY1 (well 306-902-1, Johnston, 1964). Data from U.S.G.S.

As may be seen, except for seasonal changes, the water level in this well has changed very little since 1958, with the mean being about 577 feet. This well is located closer to the major pumping center and to the pumped-storage project than is the Love Canal site. Therefore, since these factors did not affect well HY1, it is expected that they likewise do not affect flow near Love Canal. It is expected that flow at the Love Canal in the dolomite is quasi-steady state. "Quasi" in that seasonal variations of about ±2 feet are believed to be imposed on the steady-state condition in the upper part of the dolomite. According to Johnston (1964),

> "In general, water levels in the area reach their peak during the spring of the year (March and April) because of the large amount of recharge provided by snow melt and precipitation. Water levels generally reach their yearly lows near the end of the growing season during September or October."

Thus, it is expected that the water levels measured for this study should represent seasonal lows.

Following Johnston (1964),

> "Ground-water movement as it probably existed in 1962 may be summarized as follows: (1) water moves northward in a narrow area parallel to the Niagara escarpment, (2) water moves southward (down dip) in the area around the reservoir (which acts as a recharge mound and tends to deflect the water moving from the north), (3) water moves into the canal, conduits, and area of industrial pumping to discharge, and (4) water moves toward the gorge in the southwestern part of the area. The direction of ground-water movement in the Lockport Dolomite in the eastern part of the Niagara Falls area is not known."

Flow in the dolomite is in a few horizontal bedding planes. In addition to the bedding planes there are also vertical joints and small solution cavities where gypsum has been dissolved. Although most of the flow occurs in the top 10 to 15 feet of the dolomite, seven permeable zones have been identified. The dolomite ranges in thickness to a maximum of approximately 150 feet thick. Geochemically, the water in the Lockport is considered a calcium sulfate or calcium bicarbonate water.

The most probable value of transmissivity for the Lockport Dolomite is 2,300 gallons per day per foot where the saturated thickness is 110 feet, although the actual thickness of the permeable section controlling the flow was probably much less. This value of transmissivity was obtained using data from dewatering the conduit excavations. Other data indicate that the hydraulic conductivity is higher near the upper Niagara River and decreases toward the north. The storage coefficient was determined from aquifer tests and varies from 0.0003 to 0.00003.

3.3 SHALLOW SYSTEM

The shallow system at Love Canal is located in the upper units of silty sand and silt fill identified by Conestoga-Rovers and Associates (1979). It is probably bounded toward the north by Bergholtz Creek, toward the west by Cayuga Creek, and toward the south by the Little Niagara River (see Figure 3.4).

According to Leonard, et al. (1977), field observations show that the direction of surface and shallow ground-water flow (before remedial action) was from the northeast to southwest, toward the Niagara River from about Read Avenue, an area which includes about two-thirds of the site (see Figure 3.5). From about Read Avenue, north, the direction of surface water and shallow ground-water movement was toward the northwest. This is supported by vegetation damage to the north of the canal (Becker, 1979). Given these observations on ground-water movement, and noting that much of the chemical waste was placed in the southern end of the canal, it is not surprising that the problem of contaminated leachate movement into sumps and storm sewers was far more serious on the 97th Street (west) side of the landfill, and more particularly on 97th Street between Wheatfield Avenue and Frontier Avenue (near the south end of the canal). This conflicts with information given by Conestoga-Rovers & Associates (1978). They show that in the southern portion

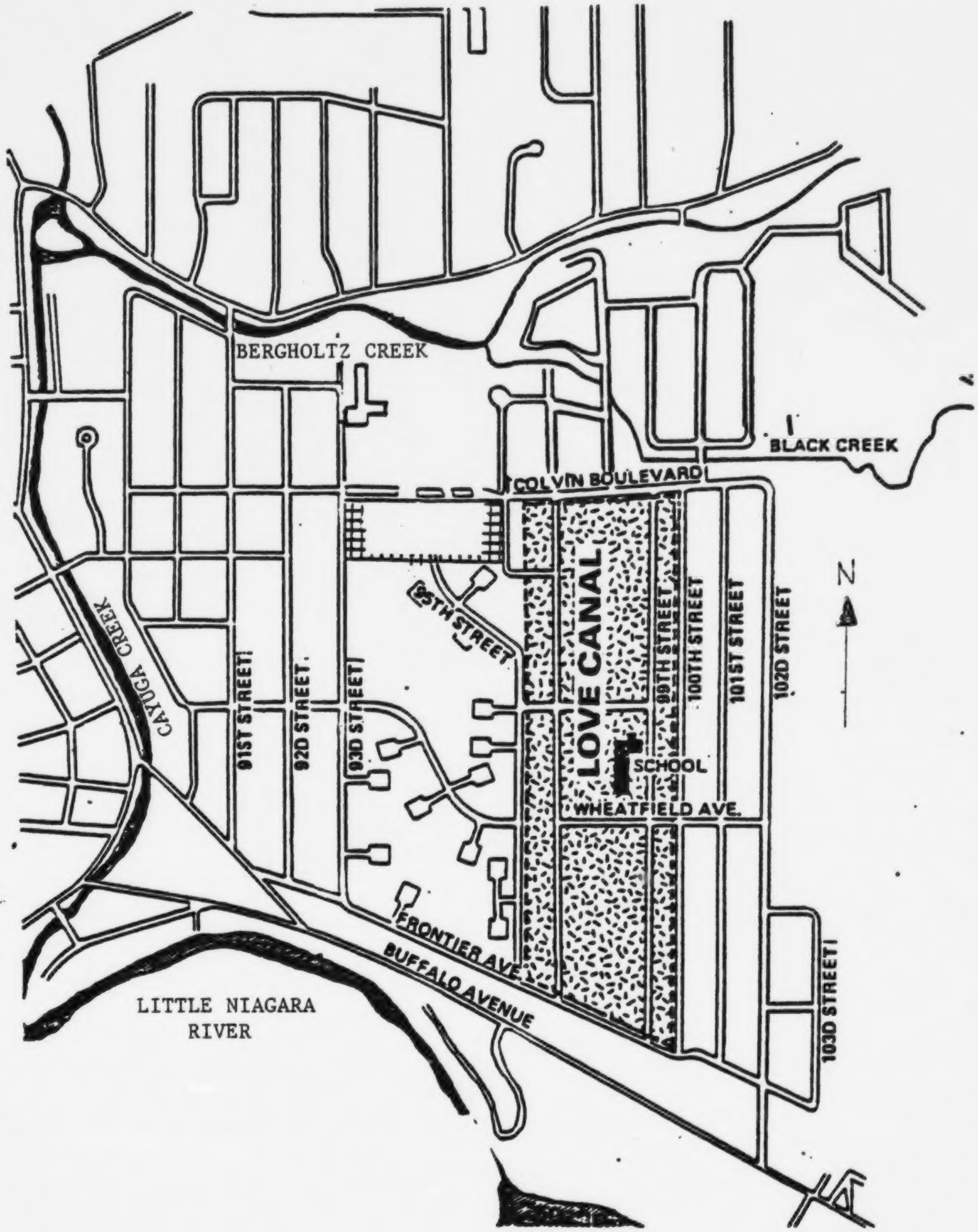


Figure 3.4 Love Canal site showing locations of creeks and rivers (after Clement Associates, 1980)

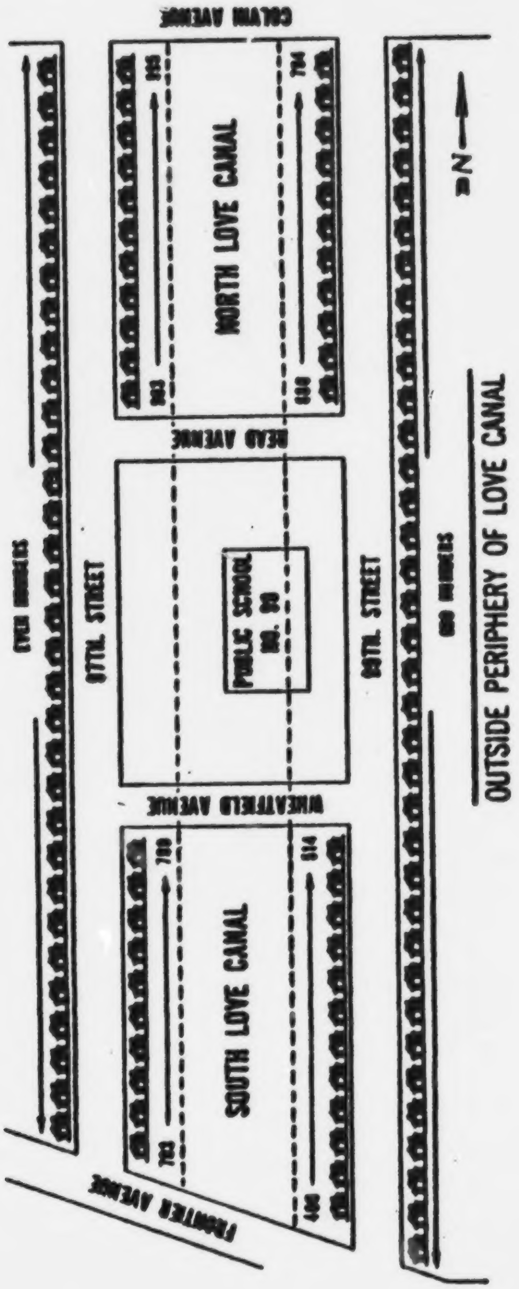


Figure 3.5 Homes surrounding the Love Canal Site (from Clement Associates, 1980)

of the landfill site, the water table was located immediately below or at the land surface, with a gradient toward the residence at 460 Ninety-Ninth Street (on the east side of the landfill). It should be noted, however, that field data indicate that the ground-water gradient was very low and that a slight mounding of water within the fill could have resulted in migration of contaminants in all directions from the fill. Also, it is not certain what effect fill around sewers and swales had on the flow system.

Leonard, et al. (1977) present water-level data that indicate the water table (before remedial action) was at higher elevation than the potentiometric surface of the deeper aquifer. Thus, over a period of time, vertical seepage of ground water may have occurred through the lowly permeable clays separating the two aquifers. It is also possible that the clays were totally breached by excavation of the canal, thus providing ready access of contaminants to the dolomite (Fred C. Hart Associates, Inc., 1978). Glaubinger, et al. (1979) point out that no evidence of contamination has been found yet in the dolomite. It is generally thought that most contaminant movement was lateral, in the shallow system above the clay layers.

This lateral movement was inhibited somewhat by seasonal changes in the water level. Johnston (1964) points out that an annual fluctuation of 5 feet is probably typical of wells in the unconsolidated deposits, with the seasonal trend being similar to that shown in Figure 3.3. Therefore, during parts of the year, certain locations within the shallow system probably became unsaturated, reducing lateral flow in those areas.

According to the U.S. Department of Agriculture (1972), detailed soil mapping was not conducted for the urban areas of Niagara Falls. What is available includes the following soil associations and characteristics:

(A) #9--Canadaigua-Raynham-Rhinebeck association; deep, somewhat poorly drained to very poorly drained soils having a dominantly medium-textured to fine-textured subsoil. Silty loam to silty clay loam (ML to CL on Unified Soil Classification) occurring generally north of Niagara River and south of U.S. 62 in the Love Canal area.

(B) #11--Odessa-Lakemont-Ovid association; deep, somewhat poorly drained to very poorly drained soils having a fine textured or moderately fine textured subsoil that is dominantly reddish in color. Silty loam to silty clay loam (ML to CL) occurring generally north of U.S. 62 and south of State Highway 31 in the Love Canal area.

(C) #2--Hilton-Ovid-Ontario association; deep well-drained to somewhat poorly drained soils having a medium-textured or moderately fine textured subsoil. Gravelly loam to silty loam to silty clay loam (SM, SC, ML or CL) with shallow (less than 6 feet) depth to bedrock occurring generally north of State Highway 31 and south of the escarpment. Note that this is the area of recharge to the Lockport Dolomite.

3.4 REMEDIAL ACTIONS TAKEN AT THE SITE

Remedial actions are discussed in detail in Clement Associates (1980). In summary, remedial action at Love Canal consisted of installing barrier drains and a clay cap. The barrier drains are 15 to 25 feet deep and 4 feet across containing French drains with installed tile pipe--ditches of about 2 feet of uniformly sized gravel, backfilled with sand. They were designed to intercept shallow lateral contaminant flow; the purpose of the clay cap was to reduce infiltration. According to information obtained from the EPA (oral communication with Jerry Thornhill, EPA, 11/17/80), construction of the French drain commenced in the southern sector in October 1978 and was completed in February 1979. The central and northern sector drains were begun June 1979 and finished December 1979.

Following the remedial action, the hydrologic units at Love Canal now consist of the following:

(1) Clay cap; 3 feet thick; hydraulic conductivity is 10^{-7}cm/s or 3.28×10^{-9}ft/s (Conestoga-Rovers & Associates, 1978)

(2) Barrier drain; gradient is 0.5%; hydraulic conductivity is 10^{-3}cm/s or 3.28×10^{-5}ft/s (Glaubinger, et al., 1979)

(3) Silty sand and silt fill; approximately 12 feet thick; hydraulic conductivity is greater than or equal to 10^{-5}cm/s or 3.28×10^{-7}ft/s (Fred C. Hart Associates, Inc., 1978)

(4) Hard clay, transition clay, soft clay; 11 feet thick; hydraulic conductivity is 10^{-8} to 10^{-9}cm/s or 3.28×10^{-10} to 3.28×10^{-11} ft/s (Leonard et al., 1977)

(5) Glacial till; 15 feet thick; hydraulic conductivity is probably similar to that of clays (Glaubinger et al., 1979)

(6) Lockport Dolomite; approximately 100-150 feet thick; transmissivity is approximately 3.5×10^{-3} ft^2/s (Johnston, 1964)

In addition to these units, storm-sewer and sanitary-sewer excavations as well as swales may act as conduits. Clement Associates (1980) defines swales as

> "...natural drainage ways in the soil substructure that formerly served as low-lying pathways for the movement of water. Over the years, the dimensions of the swales or wet areas were altered, either by natural processes, such as erosion or settlement of the soils, or by the building of housing and roads in the area. In most instances, the swales had been filled in, but they remained a preferential route of water movement in the area."

Ebert (1979) describes the swales as old drainage ways up to 10 feet deep and 40 feet wide in their original state. Possible fill material used in the swales may be disturbed soils and backfill materials that Ebert describes as

> "...not homogeneous and consists of trash, surplus soil from previous excavations, and possibly fill material that was brought to the site from other areas in the Niagara Falls region."

It should be noted that the swales' hydraulic behavior depends on the material with which they are filled, and that they will act as preferential flow routes only if they contain fill material with a higher permeability than that of the surrounding material.

SECTION 4.0 AQUIFER TESTING ANALYSIS

4.1 GENERAL

Any predictive analysis of ground-water behavior is limited by the accuracy and completeness of the data on which it is based. For a small-scale problem, such as that at the Love Canal site, data on hydrologic properties from regional studies are often inadequate. Aquifer testing provides a means for determining the properties of hydrologic units on a local scale. The properties of interest are those that characterize the ability of a unit to transmit and store water.

There are many types and variations of aquifer tests that are used in practice. Most tests, however, have several common characteristics. Normally, a complete test and analysis involves:

(1) imposing a stress on the system -- for example, pumping from a well or maintaining a constant pressure in a well;

(2) recording observations on the response of the ground-water system to the stress -- for example, water-level changes in wells near the applied stress; and

(3) estimating hydrologic parameters by comparing the observed response to theoretical models or formulas of ground-water flow behavior.

All of the theoretical models are based on simplifying assumptions and generalizations. These assumptions vary for different formulas. Consequently, it is important to assure that the conditions required for the particular test analysis are consistent with the actual field situation. Often significant deviations from theoretical conditions occur. For these cases, special care must be taken to interpret the results appropriately.

Not only must the theoretical applicability of an aquifer test be considered, but also its practicality. For example, in lowly permeable units a constant discharge test may be theoretically possible. However, the pumping rates that can be maintained might be too low to control or might require an inordinately long test. Hence, aquifer testing design involves a large degree of technical judgment that must address site-specific conditions. Furthermore, it is not unusual to have to modify testing procedures during the course of a hydrologic study. The site-specific experience gained from early tests may indicate theoretical or practical limitations.

4.2 AQUIFER TESTING PERFORMED AT THE LOVE CANAL SITE

The aquifer testing design for Love Canal evolved during the course of the field data collection activities. Indicative of this evolution is a comparison of our early testing design and the actual testing performed. Our early design was outlined in a memorandum to the prime contractor and was conceived just as the field work was beginning, before any data were collected. It is included in this report as Appendix B. The testing performed at the site is discussed in detail in JRB (1980); only a brief summary will be given here.

Aquifer testing was designed, and subsequently modified, to characterize certain aspects of the ground-water system at the Love Canal site. These included:

(1) determination of the horizontal hydraulic conductivity and storage of unconsolidated glacial units and the Lockport Dolomite;

(2) determination of the variation of hydraulic conductivity with depth in the dolomite;

(3) determination of the hydraulic connection between the more permeable upper zones of the shallow system and the dolomite; that is, the vertical component of hydraulic conductivity in the till and tight lacustrine sediments; and

(4) determination of the inter-connection (vertical hydraulic conductivity) of water-bearing zones in the Lockport Dolomite.

The tests used at the site included constant pressure tests and constant discharge tests in the Lockport Dolomite and a falling head test in the overburden and till units. Except for the constant discharge test, the results of the testing are difficult to quantify. In the remainder of this section, the purpose and limitations of each test are presented and followed by analysis of the data.

4.3 CONSTANT DISCHARGE TESTING

4.3.1 General

The most commonly used aquifer testing method in ground-water studies is the constant discharge pumping test. A number of idealized analytical models are available for describing the flow behavior under different aquifer conditions (i.e., water-table, artesian, or leaky artesian). For the Lockport Dolomite, the solution based on artesian conditions appears appropriate as a first approximation. Major assumptions included in the basic solution are: (1) that the aquifer has uniform properties (homogeneous); (2) that these properties are independent of direction (isotropic); (3) that well bore storage can be neglected; (4) that the aquifer is confined above and below; (5) that the well extends from base to the top of the aquifer (fully penetrating); and (6) that the aquifer responds as a porous media. The basic solution for the above conditions is:

$$s = \frac{Q}{4\pi T} \int_{\frac{r^2 S}{4Tt}}^{\infty} \frac{e^{-u}}{u}\, du \qquad (4.1)$$

This well know solution was first applied to well hydraulics by Theis (1935). The terms in the equation can be written in any set of consistent units, for example, in terms of feet and days for length and time, respectively:

s = drawdown in feet

r = distance from pumped well to observation well in feet

Q = discharge rate in cubic feet per day

t = time after start of pumping in days

T = transmissivity in feet squared per day

S = storage coefficient (dimensionless)

Although the long term pumping test at the site was designed to run at a constant discharge rate, the actual pumping rate declined during the test. An approximate solution for these conditions can be obtained by using the principal of superposition in conjunction with the basic solution. The procedure involves representing the variable pumping rate by a series of pumping periods having constant rates. The approximate solution is then given by

$$s = \frac{1}{4\pi T} \sum_{j=1}^{m} (Q_j - Q_{j-1})\ W(u_j) \qquad (4.2)$$

where j is the particular pumping period, m is the total number of pumping periods, W(u) is the exponential integral in equation (4.1), and u_j is equal to $r^2S/4T(t_j - t_{j-1})$. The analytical procedure is further detailed by Earlougher (1977).

Equations (4.1) and (4.2) provide forward solutions to the ground-water response. That is, knowing the hydrologic parameters and pumping rate, these formulas can predict the changes in water levels near the well.

In the field test, we have the opposite requirement. From the observed water-level changes, we would like to estimate the hydrologic parameters T and S. This is called the inverse problem. Several approaches can be used to solve the inverse problem:

(1) trial and error - solve the forward problem with different values of T and S until agreement with observed data is satisfactory;

(2) type curve methods and curve fitting - plot data in special format and compare with standard curves;

(3) statistical approaches - usually based on a variation of nonlinear least squares regression.

The trial and error method is usually time consuming but straight forward in application. For simple equations, such as (4.1), type curve matching is more convenient. For large times, equation (4.1) can be simplified and analyzed by even more convenient methods based on fitting straight lines to data plotted on semi-logarithmic paper. For a more complicated formula such as (4.2), trial and error is often too cumbersome, whereas type curve methods are generally not available. In these cases, a statistical approach is perhaps most appropriate. The statistical approach is normally based on a least squares minimization of predicted and observed data. That is, find T and S such that

$$\sum_{i=1}^{n} \left((s_o(r_i, t_i) - s_c(r_i, t_i) \right)^2$$

is minimized where s_o is the observed drawdown, s_c is the calculated drawdown, i refers to a particular observation, and n is the total number of observations. This procedure is usually implemented in a relatively simple computer program. The primary disadvantage of this method is that the user can easily lose sight of the limitations of his data. For example, obvious measurement errors that are easily discovered by type-curve fitting are overlooked by a computer. As a result of this limitation, it is best to plot all observed data and compare with calculated curves based on the statistical match.

4.3.2 Analysis of Observation Well Data

Because the long term pumping test at Love Canal was conducted with a declining discharge rate, the data was analyzed using equation (4.2). The statistical approach was used to determine T and S. To further illustrate the assumptions and limitations of this analysis Table 4.1 is provided. This table summarizes the major assumptions of equation (4.2), the corresponding field conditions, and justifications for any discrepancies between the first two.

As previously indicated by using equation (4.2), it is assumed that the variable discharge rate can be approxi-

Table 4.1 Summary of major assumptions for the variable rate pumping test model of Lockport Dolomite.

Model Assumption	Actual Condition	Comment
porous media	fracture and solution media	most of the permeability is along bedding planes, for long times and far away from the pumping well porous media approximation should hold
isotropic media (areally)	probably isotropic	no evidence in literature review suggested anisotropic conditions in areal dimensions
homogeneous media	heterogeneous	existing studies show that the lockport has properties that vary widely from point to point; deviations from ideal behavior will provide a measure of the heterogeneity
uniform properties throughout thickness	variable with depth	reasonable approximation and consistent with data availability
confined aquifer	leaky artesian	because of lowly permeable confining beds, leaky effects will be negligible for test period
infinite aquifer	bounded aquifer	boundary effects should be small during test and detectable in observed data, if present
no well bore storage	negligible	high transmissivity, small radius well

Table 4.1 (continued)

Model Assumption	Actual Condition	Comment
fully penetrating well	partially penetrating well	well is finished in primary water bearing zones
step like pumping variations	continuously variable rates	reasonable approximation given discharge rates recorded for test

mated by a series of pumping periods having constant rates. This gives the appearance of a step-like function as shown in Figure 4.1. Also shown in Figure 4.1 are the observed rates measured during the test. It should be noted that the observed rates are essentially point estimates, being based on only a few to a few tens of seconds worth of measurement. Consequently, the approximate step is consistent with the accuracy of the data.

During the pumping test, water levels were measured in 14 observation wells and in the pumping well. Measurements were taken at three observation wells for two hours after the pump was shut down. With all this data, there are several alternative ways to partition it for analysis. Two obvious ways are:

(1) Match all the observations using one transmissivity value and one storage coefficient value (Case A).

(2) Match the data for each well independently, calculating a separate T and S for each well (Case B).

Both of the methods were used in this analysis. Comparing the results of both cases provides a measure of validity in the analysis.

Before matching the observed drawdowns, the pumping test data was checked for consistency. On the basis of this check, it was decided not to include the data from observation wells 39 and 49 and the pumping well 72 (see Figure 4.2 for location) in the analysis. The pumping well

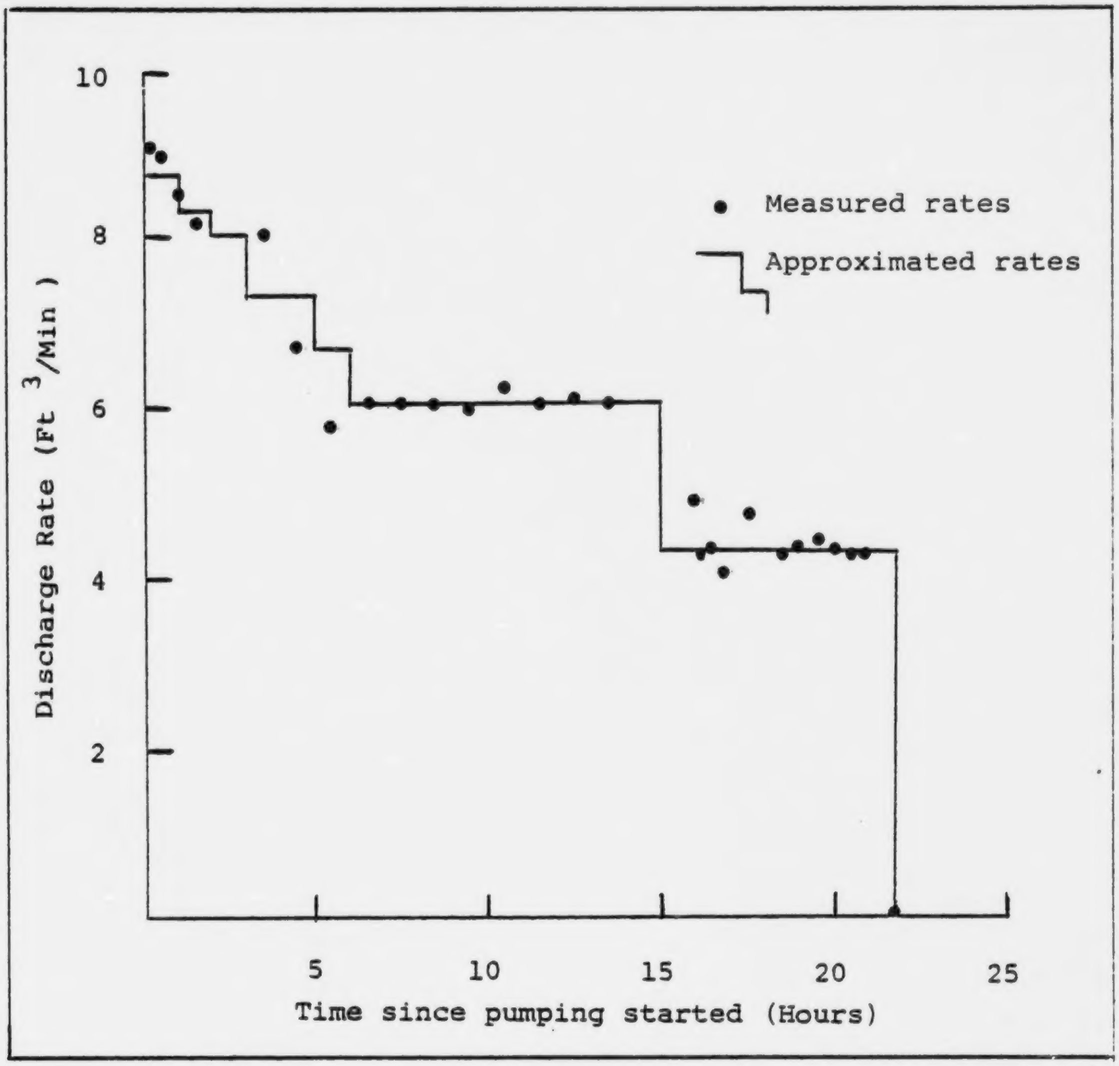


Figure 4.1 Plot of observed discharge rates and approximate rates used to analyze the data.

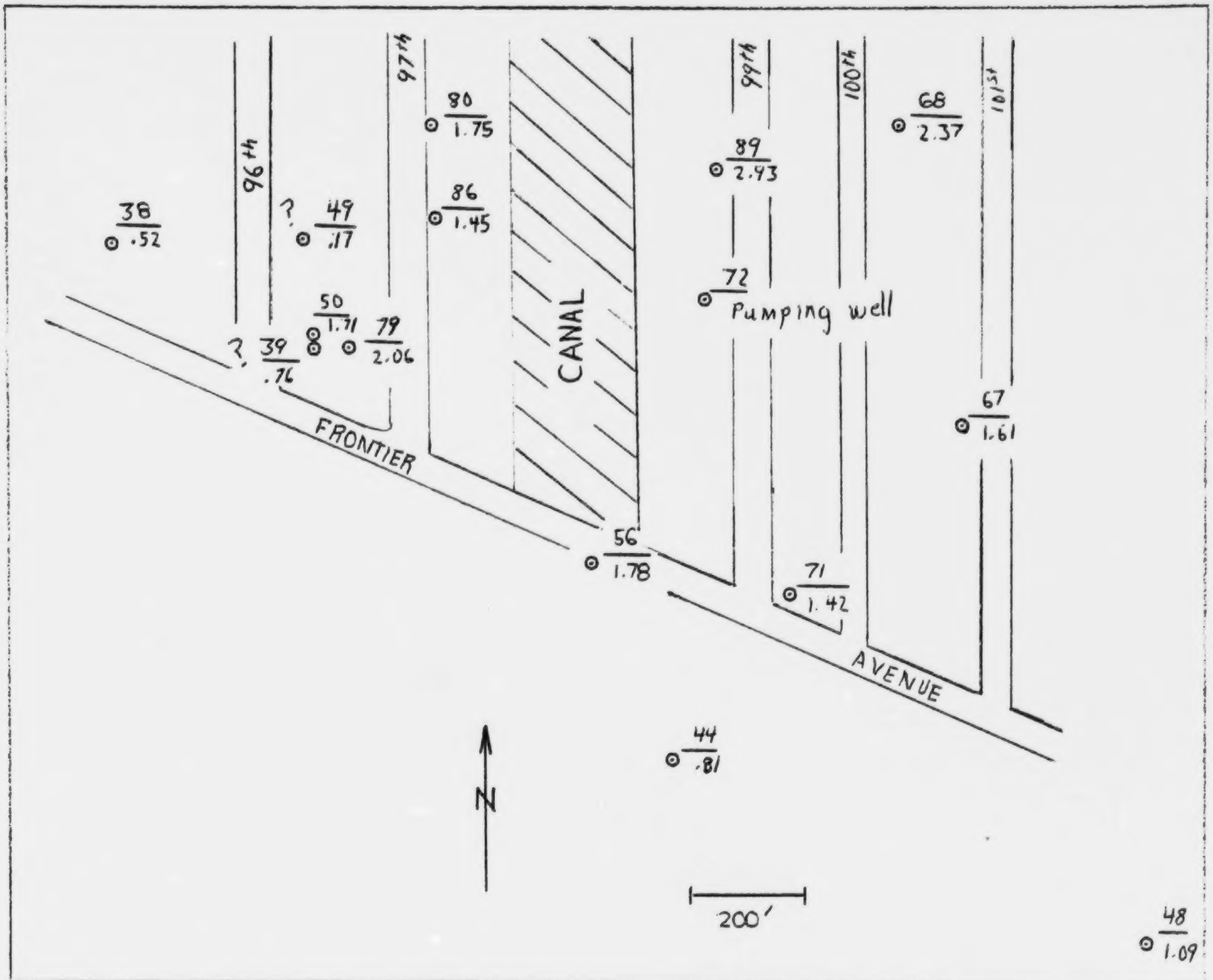


Figure 4.2 Map showing location of observation wells and pumping well for pumping test on Well 72, 13-14 OCT 80. Number above line refers to well, number below line refers to drawdown after about 6 hours pumping.

data were not used, because of complicating factors discussed in the following section. Data from wells 39 and 49 were inconsistent with the other data - both appeared to either have an error in the static level measurement or to be poorly connected to the water-bearing zones. The drawdowns in both wells were very low in comparison to nearby wells. Figure 4.2 shows the drawdowns measured in each well approximately 6 hours into the pumping test. The apparently low drawdowns in wells 39 and 49 are evident in this figure.

Drawdown data for the remaining 12 wells were reduced and prepared for use in an automatic inverse program. Typical drawdown data for a single well is shown in Figure 4.3. As can be seen, the data reflects (by dips) the effects of pumping rate variation at about 4 and 15 hours in the pumping test. The sharp decline in drawdown shown at the end represents the recovery period after the pump was shut off.

The results of matching the data are presented in Table 4.2. Using all available data and matching all of the wells with one T and S led to values of 0.015 ft^2/s and 1.49×10^{-4}, respectively. The mean deviation between observed values and calculated values using the above T and S was 0.39 feet. Fitting the individual well data led to better matches of the data. For this case the transmissivity values were between 0.011 and 0.038 ft^2/s and the storage

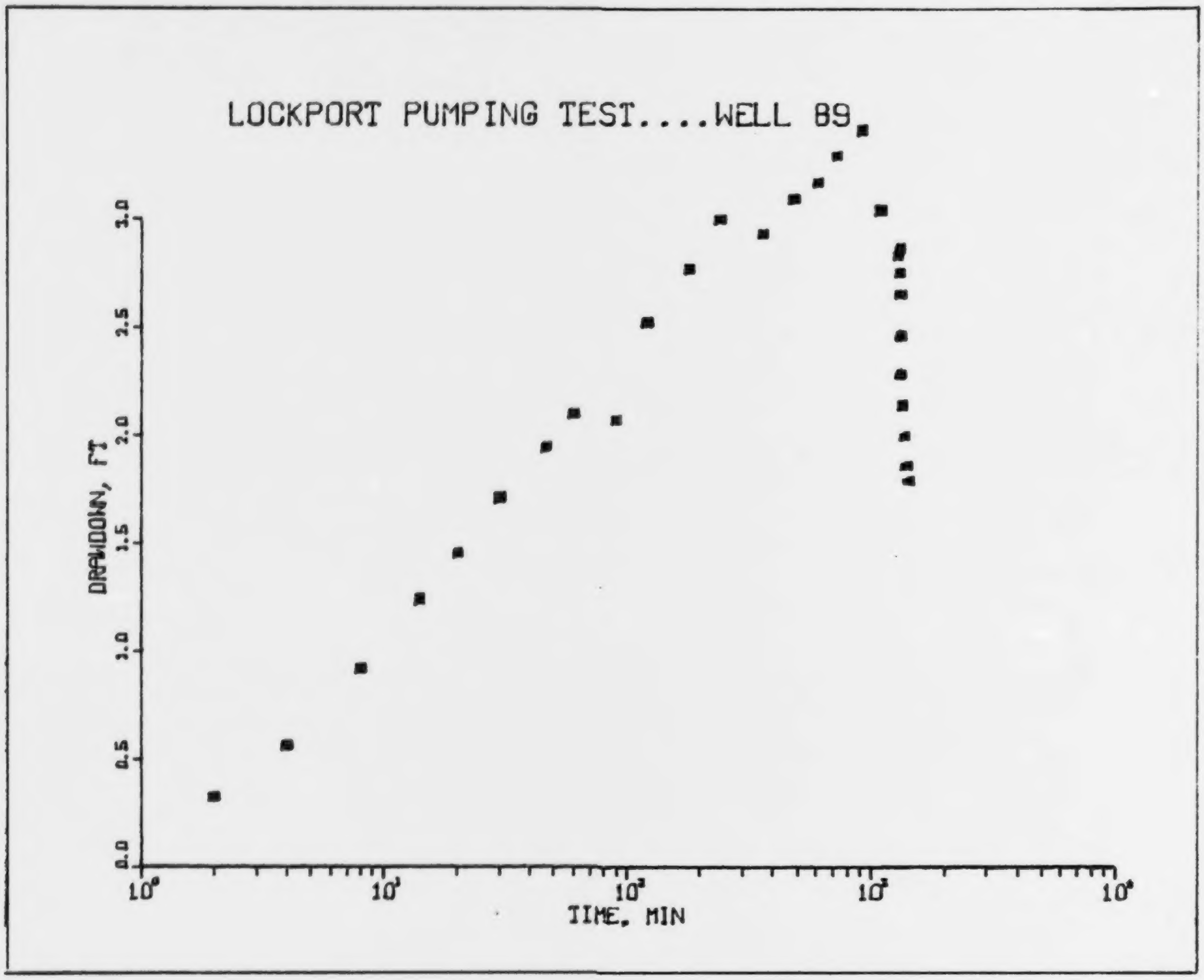


Figure 4.3 Typical semi-log time drawdown plot of observed data (including recovery) for 13 OCT 80 pumping test on well 72.

Table 4.2 Summary of results for pumping and recovery test analysis.

Matching group	Well	T ft^2/s	$S \times 10^{-4}$	mean deviation (ft)
CASE A All wells together	All	0.015	1.490	0.390
CASE B Individual wells	38	0.038	2.370	0.032
	44	0.033	1.650	0.045
	48	0.027	0.343	0.064
	50	0.019	0.483	0.105
	56	0.020	0.825	0.052
	67	0.018	1.750	0.083
	68	0.011	1.330	0.063
	71	0.020	1.500	0.067
	79	0.017	0.428	0.108
	80	0.015	1.290	0.083
	86	0.018	3.120	0.162
	89	0.011	2.000	0.209
	Average	0.021	1.420	---

coefficient values were between 0.343×10^{-4} and 3.12×10^{-4}. As noted, the matches on individual wells were better -- mean deviations for each well were between 0.032 and 0.209 feet. Typical matches for both Case A and Case B are shown in Figures 4.4 and 4.5. Similar figures for both cases and all 12 wells are attached as Appendix C.

As mentioned, recovery data was measured in wells 71, 86, and 89. These data were included in the above analysis, and were also used to calculate T and S values. For these results, the transmissivity values averaged 0.015 ft^2/s -- the same as above. The storage coefficient values averaged 4.13×10^{-4} -- higher than above. Because those estimates are based on a short period of recovery measurements, the results are not significantly different from the complete analysis.

The computed values for T and S resulted in a small range (about a half and one order of magnitude respectively). The range in values indicates that the Lockport Dolomite is heterogeneous (properties vary from point to point). However, on the scale of the test, about ½ mile, the variation is relatively small for a carbonate aquifer. The results of this analysis show the transmissivity values for the site are higher than the average values reported by Johnston (1964) for the Niagara area. However, the high values are consistent with his

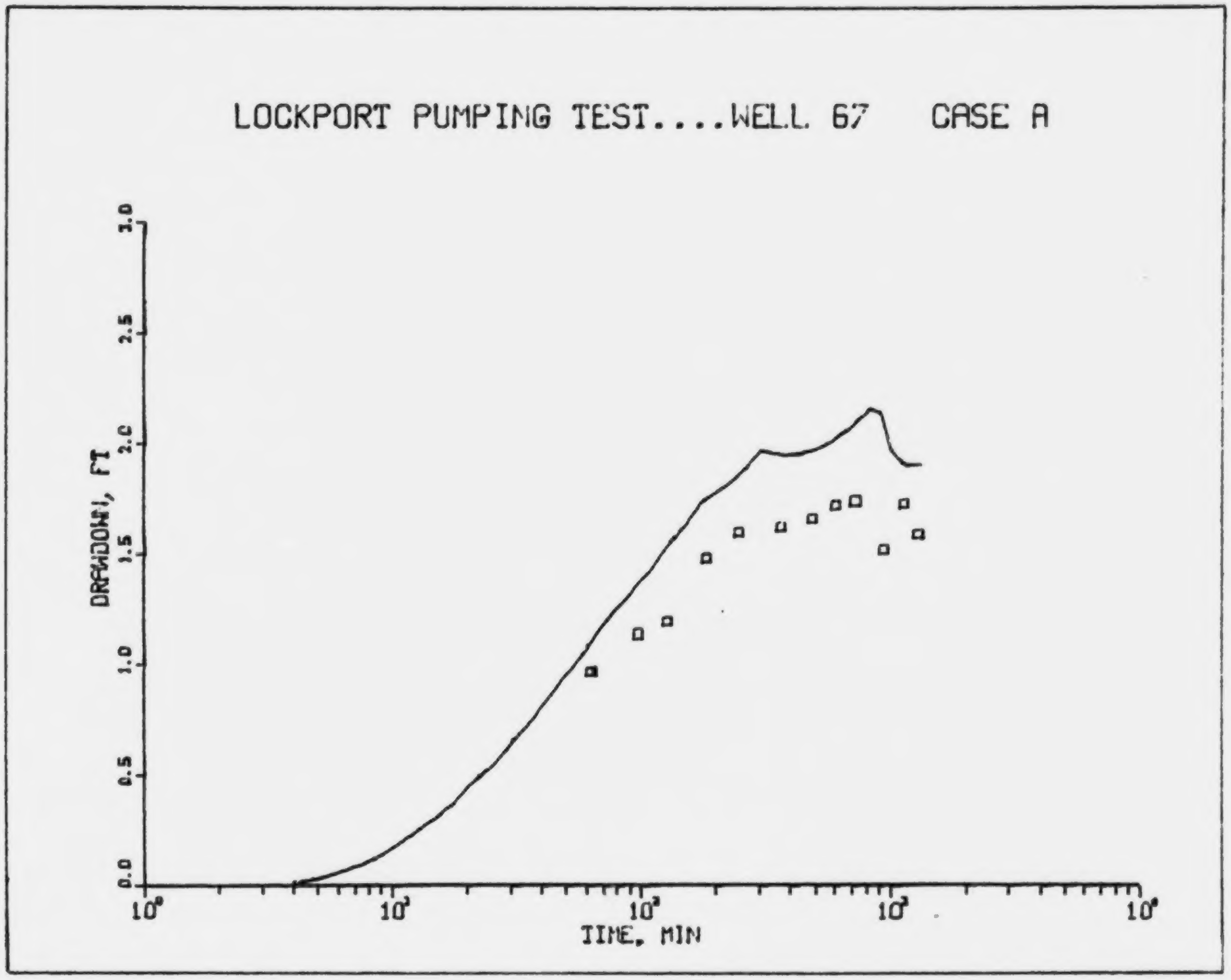


Figure 4.4 Typical plot of observed drawdowns and theoretical drawdowns using T and S fitted to data from all wells. Note that the comparison indicates that the T for this well should be higher than that used to compute the theoretical curve. Agreement for Case A matches is generally poor, indicating inhomogeneity in the aquifer.

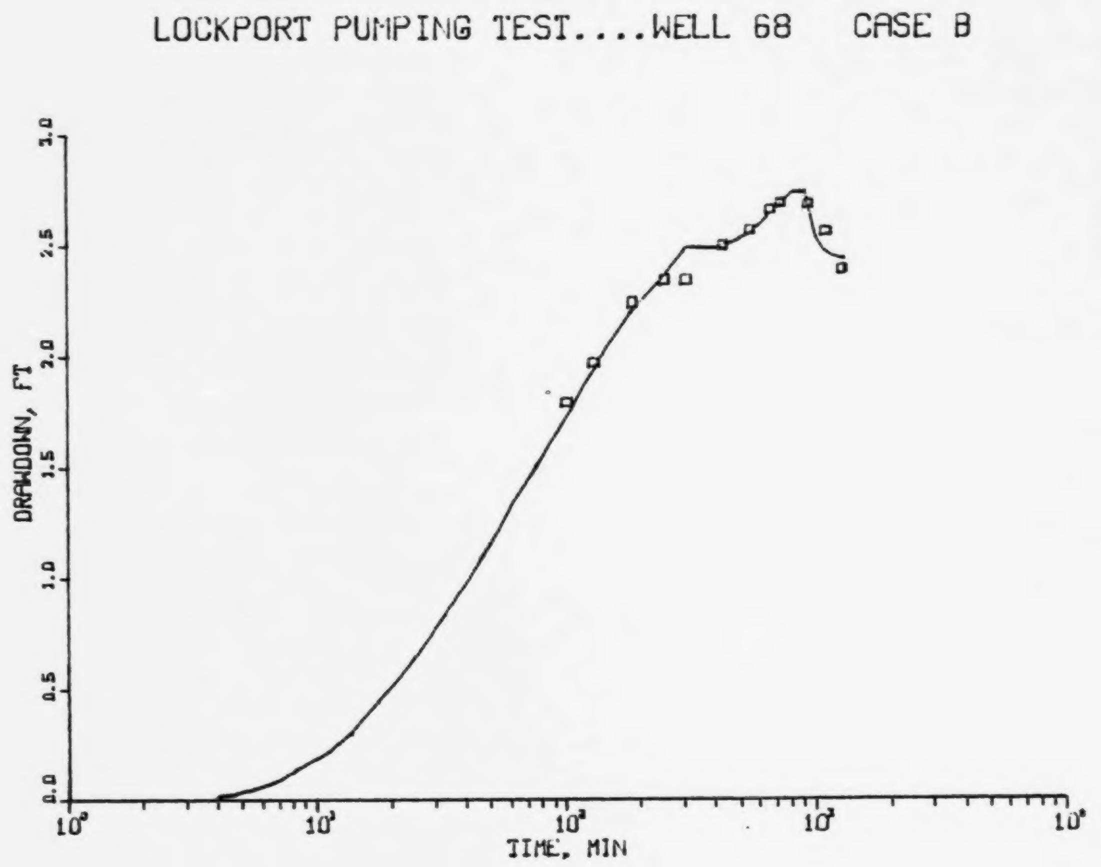


Figure 4.5 Typical plot of observed drawdowns and theoretical drawdowns using T and S fitted to data from this well only. Agreement for Case B matches is generally very good.

suggestion that the Lockport Dolomite is more permeable near the upper Niagara River. The storage coefficient values calculated for the site are similar to those reported by Johnston (1964). Observations were also recorded in the overburden well at site 72. During the test the water levels were not affected by pumping in the dolomite well.

4.3.3 Analysis of Pumping Well Data

The analysis of the data in the pumping wells is not as straightforward as with the observation wells. The reason for this is that at the beginning of the test the flow is fracture (or bedding plane) controlled. This, in part, explains the discrepancy between the two pumping tests conducted in well 72 (JRB, 1980). In the first test, a constant flow rate of 5.35 ft^3/min resulted in only a few feet of drawdown. In the second test, with an initial flow rate of 8.70 ft^3/min, drawdowns of 15-20 feet occurred within a few minutes after pumping started. For the second test, the well was partially filled with grout, but the main permeable section was still open. The difference in water level responses for the two tests suggests that some near well turbulent flow effects in the bedding planes could have resulted in the lower apparent transmissivity for the second test. Unfortunately, the lack of any data after the first few hours makes this suggestion difficult to verify.

The first test does exhibit typical fracture flow behavior in the early time data. Figure 4.6 is a log-log plot of drawdown versus time. On this graph, two flow periods can be identified. During the first few minutes, the data fall on a straight line having an approximate slope of ½. This slope can occur when a well is drawing water from a single or few parallel fractures (Gringarten and Ramey, 1974). In this case, we suspect a few major bedding plane zones produced flow behavior typical of horizontal fractures. The second flow period seen on the graph is the radial flow period, typical of flow in porous media. The second part of the flow period can be analyzed for T using Jacob's method (Jacob, 1950). The transmissivity determined in this manner was 0.084 ft^2/s, which is slightly lower than any of the values previous calculated for observation wells. Because of the early time nonradial flow behavior, the storage coefficient cannot be calculated from this data.

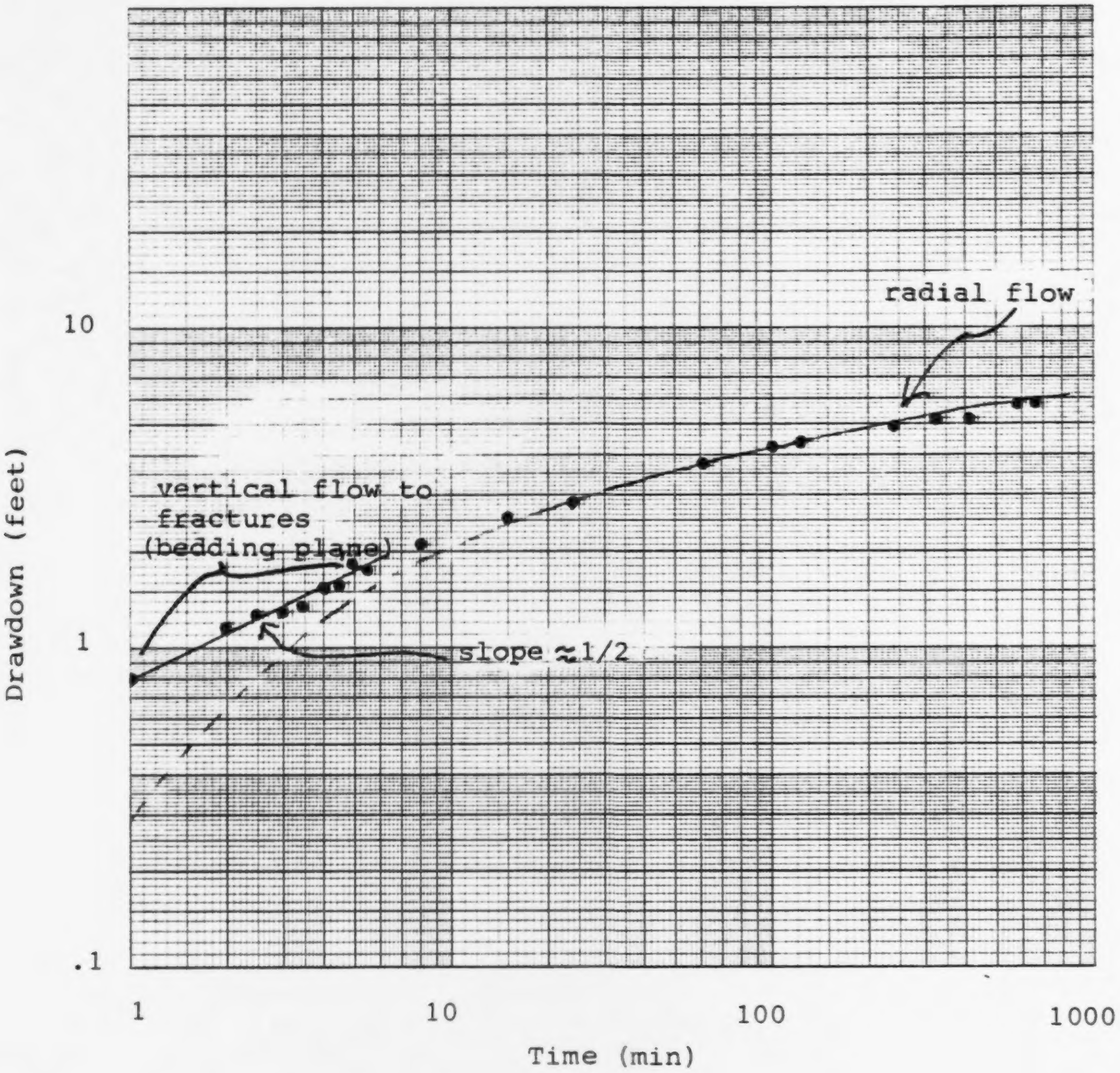


Figure 4.6 Log-log plot of time drawdown data for 3 OCT 80 pumping test on well 72; showing two periods of flow - the first few minutes dominated by vertical flow to bedding planes intersecting the well and a later period dominated by radial flow to the well.

4.4 SLUG TEST ANALYSIS OF WELLS IN UNCONSOLIDATED MATERIALS

Slug tests or falling head tests provide a method for determining field hydraulic conductivities from single wells. In general, these tests provide semi-quantitative values of hydraulic conductivity. However, in unsaturated material or lowly permeable material, these tests may be the only practical method. There are several variations of these tests which are described by the Bureau of Reclamation (1977). Basically, the test involves quickly injecting a known volume of water into a well and measuring the water-level decline.

The procedures for the slug tests conducted at the site are described by JRB (1980). The wells were located on the east side of the basketball court on 92nd Street in a relatively undisturbed area. For this series of tests, a cluster of four wells, completed at different depths, was drilled. Figure 4.7 shows the geologic log of the deepest well and the zones in which each was open (after JRB, 1980). No significant water was observed in any of the four wells after drilling, although at the time of the test (about nine days later), the two intermediate wells had measurable water levels in them. Well T2 (depth 16.6 feet) had recovered 2.2 feet and well T3 (depth 26.4 feet) had recovered 6.41 feet. Based on nearby static water levels (discussed in a later section), we assume that the water level at full

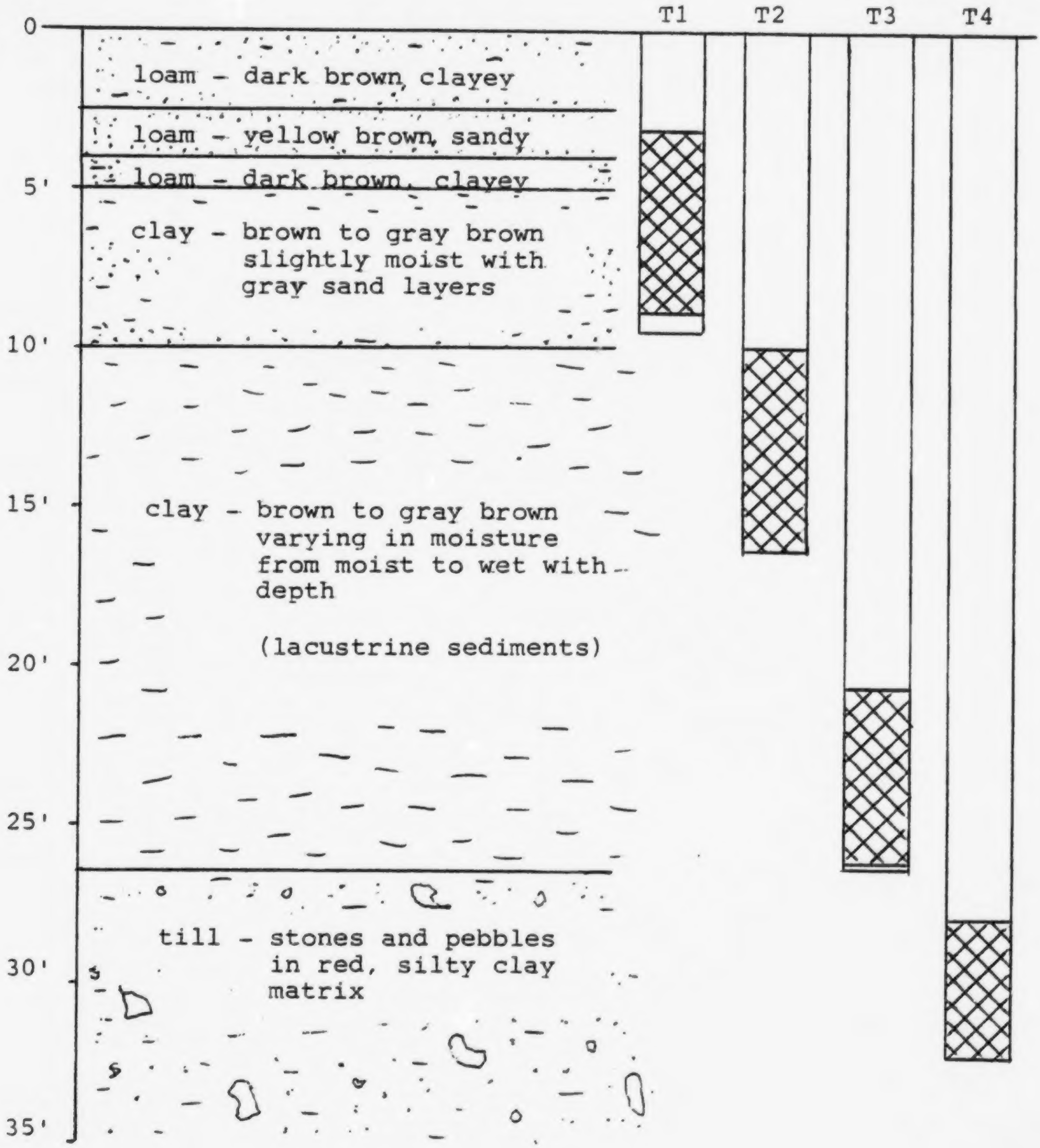

T1
T2
T3
T4
0
5'
10'
15'
20'
25'
30'
35'
loam - dark brown, clayey
loam - yellow brown, sandy
loam - dark brown, clayey
clay - brown to gray brown slightly moist with gray sand layers
clay - brown to gray brown varying in moisture from moist to wet with depth
(lacustrine sediments)
till - stones and pebbles in red, silty clay matrix

Figure 4.7 Geologic log for location of cluster wells (after JRB, 1980). Also shown are the depths and position of screened intervals for each well.

recovery should be about 8 feet below land surface in each well. The relatively small amount of recovery in the nine day period is indicative of the low permeability of the units tested.

Several alternative approaches can be used to determine the hydraulic properties from the slug test data. For the three deeper wells, assumed to be lower than the water table, a general analytical solution is available (Cooper et al., 1967). This solution assumes that the slug of water is injected instantaneously in a well of finite diameter in a confined aquifer. In order to use this method to determine soil properties, data is matched with theoretical type curves. For the data from these tests, however, the drawdown is so slight that the type curve comparisons would be very imprecise.

In order to analyze the data, it was decided to approximate the test as a constant head test. The head in the well does decline (and the rate of decline is used to calculate flow rates), but the decline is less than 15% in each case. Hence, the approximation appears appropriate. The solution for the constant head test is given by equation (4.1). All of the assumptions previously stated for this equation still hold, only now, Q varies with time and s is constant. For $u = r\ S/4Tt < 0.05$, equation (4.1) simplifies to

$$s \simeq \frac{Q}{4\pi T}(-0.5772 - \ell n\ u) \qquad (4.3)$$

which can be rearranged to determine transmissivity as

$$T = \frac{2.30}{4\pi s\Delta(1/Q)/\Delta\log_{10}t} \qquad (4.4)$$

The part of the equation, $\Delta(1/Q)/\Delta\log_{10}t$, is the slope of the straight line portion of plot of observed inverse-flow rates versus log time. Figures 4.8-4.10 show 1/Q versus log time for the three deepest cluster wells, T2, T3, and T4. In each of these cases the discharge was calculated by

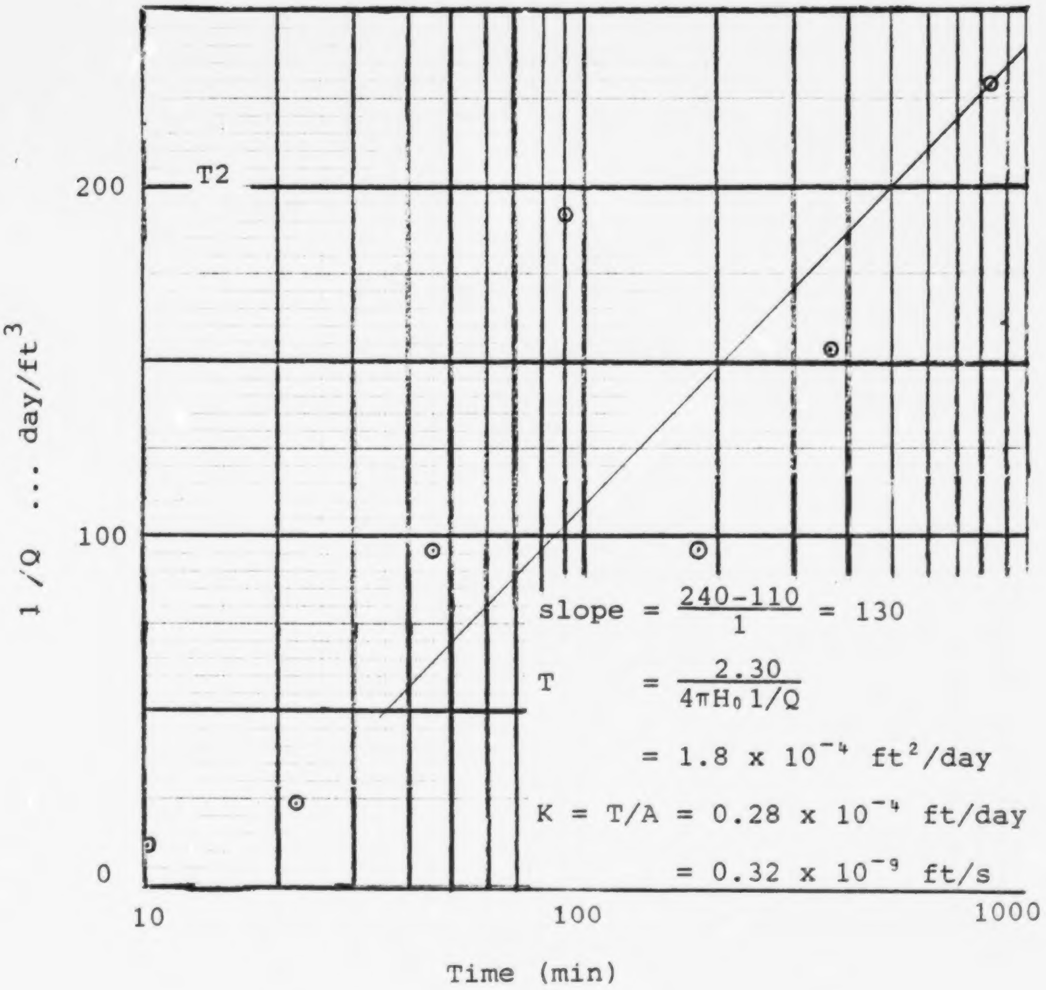
$$Q = \frac{(H_1-H_2)r_w^2\pi}{(t_2-t_1)} \qquad (4.5)$$

where H is hydraulic head and the subscripts 1 and 2 refer to sequential measurement numbers. As can be seen in Figures 4.8 and 4.9, the values of 1/Q are somewhat erratic but a general trend can be deduced. From this trend the hydraulic conductivities in wells T2 and T4 are estimated to be 0.32×10^{-9} and 0.25×10^{-9} ft/s. The hydraulic conductivity is calculated by using T from equation (4.4) and

$$K = T/A \qquad (4.6)$$

where A is the length of the open interval of the well.

For well T3 shown in Figure 4.10, the behavior is not ideal. Qualitatively, the data show well T3 to be more permeable than the other two wells. However, the decrease in 1/Q and subsequent leveling of 1/Q indicate that some of the assumptions for equation (4.1) do not hold. A



$$\text{slope} = \frac{240-110}{1} = 130$$

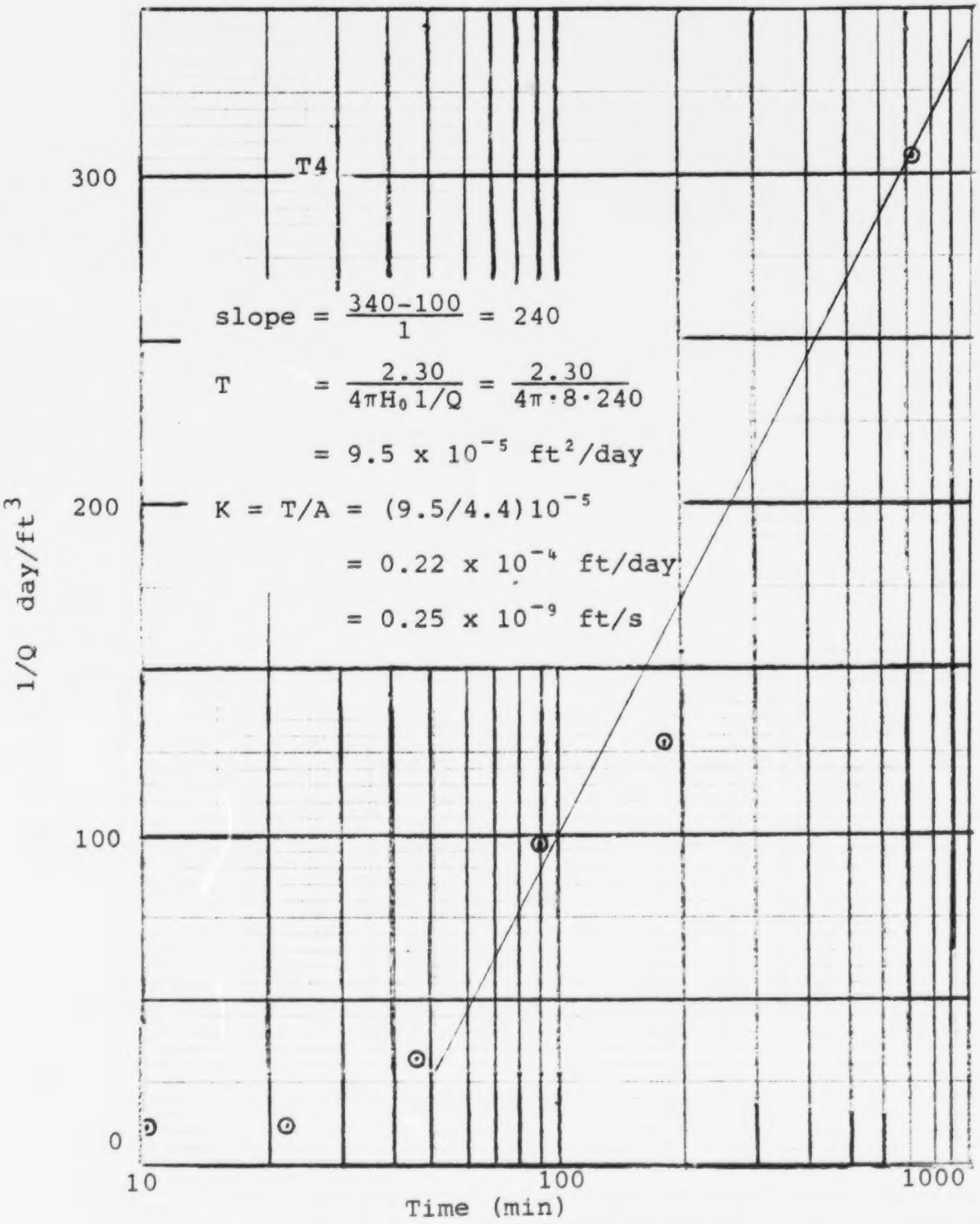
$$T = \frac{2.30}{4\pi H_0 \, 1/Q}$$

$$= 1.8 \times 10^{-4} \text{ ft}^2/\text{day}$$

$$K = T/A = 0.28 \times 10^{-4} \text{ ft/day}$$

$$= 0.32 \times 10^{-9} \text{ ft/s}$$

Figure 4.8 Analysis of slug test in soil well T2 using constant head approximation.



$$\text{slope} = \frac{340-100}{1} = 240$$

$$T = \frac{2.30}{4\pi H_0 \, 1/Q} = \frac{2.30}{4\pi \cdot 8 \cdot 240}$$

$$= 9.5 \times 10^{-5} \text{ ft}^2/\text{day}$$

$$K = T/A = (9.5/4.4)10^{-5}$$

$$= 0.22 \times 10^{-4} \text{ ft/day}$$

$$= 0.25 \times 10^{-9} \text{ ft/s}$$

Figure 4.9 Analysis of slug test in soil well T4 using constant head approximation.

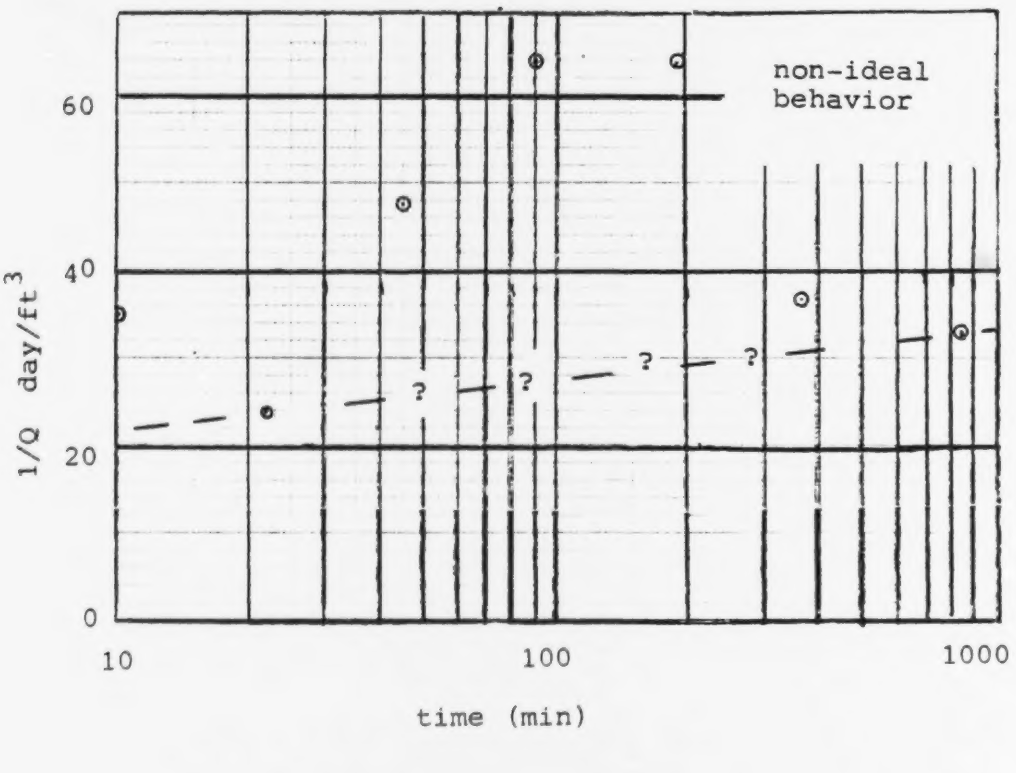


Figure 4.10 Analysis of slug test in soil well T3 using constant head approximation. Note, non-ideal behavior. This can be partially explained by the presence of a lowly permeable skin resulting from augering operations.

possible explanation for the non-ideal behavior is that the augering operation resulted in a layer of lowly permeable material lining the well (referred to as a skin). This could occur if a permeable zone occurs in the upper part of the open interval of the well.

To further test this hypothesis, a numerical model capable of simulating the well damage was used to match the observed data. The numerical model is documented and described by INTERCOMP (1976). A fair match was achieved by specifying a general unit hydraulic conductivity of 1.2 x 10^{-9} ft/s and a lowly permeable (0.12 x 10^{-9} ft/s) zone ½" thick around the well bore. A comparison of observed simulated drawdowns is shown in Figure 4.11.

For the shallow well none of the above methods of analysis can be used. For this well, almost certainly, is completed above the water table. An equation for this type of test conducted above the water table is provided by BLM (1977). The equation for K may be determined from

$$K = \left[\frac{r_i^{\,2}}{2A\Delta t} \; \frac{\sinh^{-1} \frac{A}{r_e}}{2} \; \ell n \left(\frac{2H_1 - A}{2H_2 - A} \right) - \ell n \left(\frac{2H_1 H_2 - AH_2}{2H_1 H_2 - AH_1} \right) \right] \qquad (4.7)$$

where K = average hydraulic conductivity of open interval

A = length of open interval

r_i = inside radius of the open interval

r_e = effective radius of the open interval

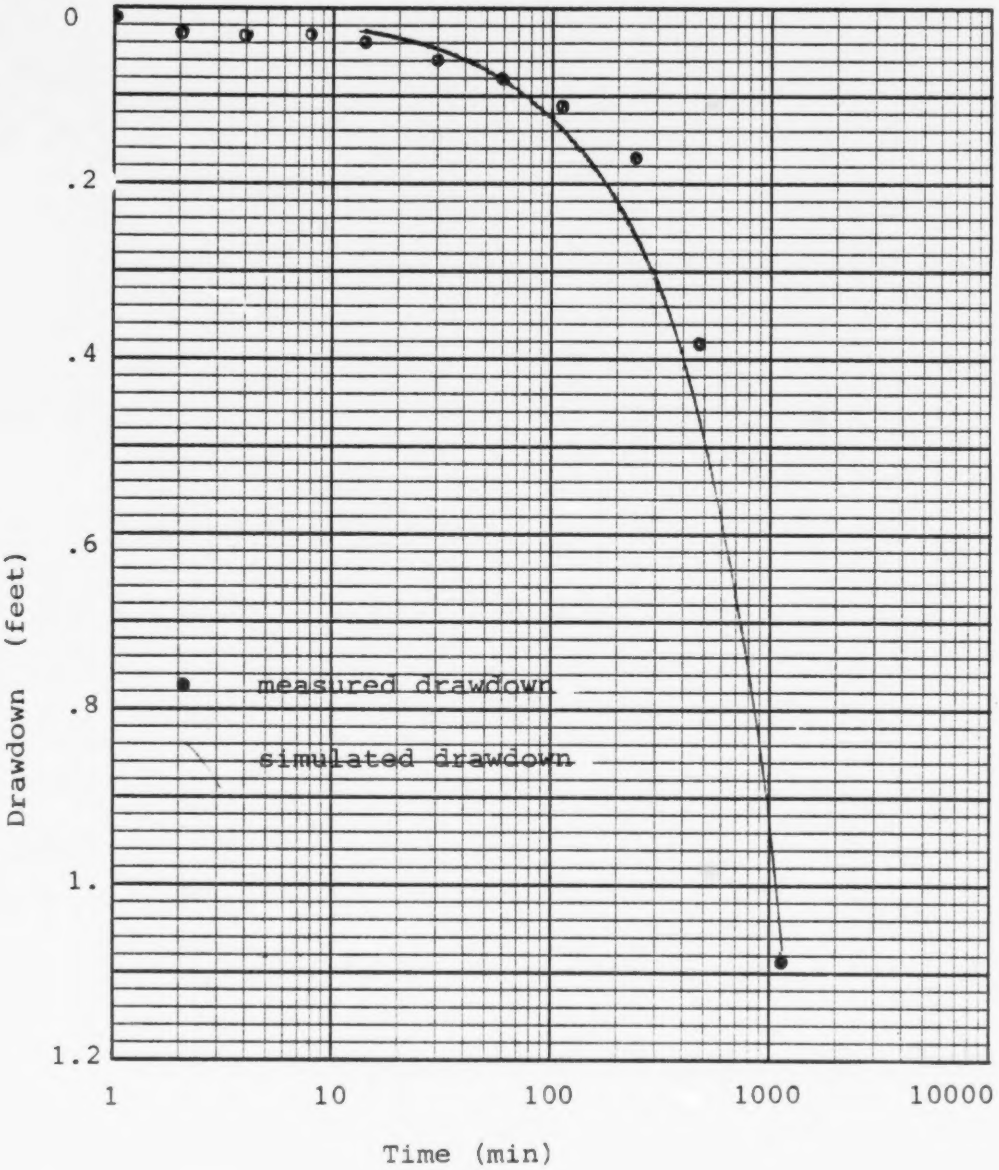


Figure 4.11 Slug test results for well T3 showing observed and computed drawdowns. Simulated results included the effect of a low-permeability skin.

and other terms are as previously defined. Again, any consistent set of units can be used in calculations. Depending upon the interval Δt chosen for calculation of K, the values ranged from 0.74×10^{-9} to 2.5×10^{-9} ft/s. Unfortunately, the original reference for equation (4.7) is an internal 1949 BLM memorandum and the basic assumptions of the equation are not described in BLM (1977).

The estimated values of hydraulic conductivity based on the above analysis for the four soil cluster wells are listed in Table 4.3 together with the method of analysis and its major assumptions. With the limitations of the methods used to determine these values, the estimates should be considered semi-quantitative. Basically, all of the unconsolidated materials tested had hydraulic conductivity values on the order of 10^{-9} ft/s. The glacial till and upper zone of the lacustrine sediments had the lower values of K, whereas the lower portion of the lacustrine sediments and the shallow well had the higher values. Each of the four units would have to be classified as very lowly permeable. Only the low permeability of the shallow well was unanticipated. It had been planned to be finished in the upper silty material, but from the log shown in Figure 4.7 it was clearly finished in the more clayey material.

Table 4.3 Summary of slug test analyses for cluster wells in unconsolidated materials.

Well #	Unit	K(ft/s)	Method of Analysis	Assumptions
T1	Silty Clay	$>0.74\times10^{-9}$ $<2.5\times10^{-9}$	BLM (1977) p. 284-285	Above water table, isotropic material, homogeneous material; assumption not well documented in reference.
T2	Lacustrine sediments	0.32×10^{-9}	constant head	Isotropic, homogeneous material, horizontal flow, drawdown very small water table 8 ft below land surface
T3	Lacustrine sediments	1.2×10^{-9}	numerical simulation of slug test	Well bore storage, ½" thick skin ($K=0.12\times10^{-9}$ ft/s), isotropic, homogeneous aquifer, open interval at 10.7-26.2 ft and water table at 8 ft below land surface.
T4	Till	0.25×10^{-9}	constant head	(same as for T2)

4.5 OTHER AQUIFER TESTING AT THE SITE

The tests described in the preceding sections were the only ones that provided quantitative or semi-quantitative estimates of hydraulic properties at the site. A series of slug, constant discharge, and constant head tests was conducted on zones in the Lockport Dolomite. The tests involved the use of inflatable packers to isolate sections of the deep dolomite wells for testing. The wells involved in the tests were 56, 77, 86.

The objectives of the packer tests were to determine the variability of horizontal hydraulic conductivity with depth and the degree of hydraulic connection among the permeable zones. Unfortunately, the tests were generally inconclusive. Several factors contributed to ambiguous results:

(1) during some of the tests, proper seals were not maintained by the packers;

(2) some of the tests were conducted during the drilling and pumping of nearby wells;

(3) no replicate tests were conducted; and

(4) field records of necessary data such as flow rates were incomplete.

Because of these limitations, the data are not interpreted.

4.6 SUMMARY OF AQUIFER TESTING RESULTS

The results of the aquifer testing partially fulfilled the original test objectives. The following conclusions can be drawn from the analysis:

(1) The 22 hour discharge test in the Lockport Dolomite provided a field average transmissivity of 0.015 ft^2/s and storage coefficient of 0.00015. These values are consistent with other values determined for the Lockport Dolomite in the Niagara vicinity.

(2) Because many of the observation wells were completed only a few feet into the dolomite, and because they responded quickly to the pumping from a much deeper well, the upper permeable zones of the dolomite appear to have significant vertical permeability.

(3) The Lockport Dolomite is heterogeneous but less so than would normally be anticipated for carbonate aquifers.

(4) The packer test results for the dolomite were inconclusive. Consequently, the regional observations of Johnston (1964) regarding the variation of hydraulic conductivity with depth are still assumed applicable to the site. Examination of the core description also supports Johnston's contention that the primary water bearing zones are located in the upper zones of the Lockport Dolomite.

(5) The slug tests in the overburden wells provided an estimate of the hydraulic conductivity of the lacustrine sediments and till. Both values are on the order of 10^{-9}ft/s and indicate relatively impermeable material.

(6) The shallow material tested at the slug test site was also relatively impermeable (on the order of 10^{-9}ft/s). However, this unit was quite clayey. Because the shallow silty-sandy units are highly variable, this one estimate is probably not representative of the shallow system at the site.

(7) No estimates of storage properties for the overburden wells could be determined from the slug tests.

SECTION 5.0 WATER LEVEL MEASUREMENTS

5.1 GENERAL

As indicated in the literature review section, insufficient data were available to construct detailed potentiometric maps for the Love Canal area. As part of the current study, 178 wells were drilled, with about half in the shallow system and the other half into the Lockport Dolomite. During the period 23 Oct 1980 to 24 Oct 1980 a well inventory was performed. The results of these water-level measurements are presented in Plates 2 and 3. For reference, the study area is indicated on Plate 1, with the dashed boarder approximately enclosing the same area as Plates 2 and 3.

5.2 LOCKPORT DOLOMITE

Plate 2 shows the potentiometric surface for the Lockport Dolomite in the Love Canal area. Also indicated are the values of the data points. The precision of the water-level measurements was within one tenth of a foot. However, for confined aquifers, barometric and earth tide effects can cause water-level variations of several tenths of a foot (Walton, 1970). Because these potential variations were not removed from the field data, a contour interval of 0.5 feet was used.

As may be seen, the water levels generally vary between 564 to 565 feet with a small gradient toward the south and southwest. This is in agreement with the potentiometric surface given in Plate 1, with more detailed flow features shown in Plate 2. It is very difficult to interpret such a flat potentiometric surface on a local scale. The steeper contours to the southeast could be due to a local low-permeability zone in the Lockport Dolomite. The slight bending of the 564 ft. contour to the south probably results from the combined influences of the Lockport Dolomite discharging to the Niagara River and the bending of the river to the south as one goes up river.

During drilling operations and in conjunction with packer testing, water levels were measured to assess variations in head with depth. The water levels measured during coring showed variations of one to two feet. Because the water levels were affected by drilling operations, no recognizable trend can be deduced. Likewise, water levels recorded using packers were inconclusive. Only a few zones were measured in well 72 and no replicate measurements were made. Consequently, the data collected in this study were insufficient to determine the variation of head with depth in the Lockport Dolomite in the Love Canal site. It should be noted that during packer testing, Johnston (1964) observed a decrease in head with depth in the dolomite. The wells he tested were located near the pump-storage reservoir and the Niagara escarpment, which is a recharge area.

Love Canal is located in a probable discharge area, for which heads would more likely increase slightly with depth.

5.3 SHALLOW SYSTEM

The potentiometric (water-table) surface for the shallow system is shown in Plate 3. For several reasons this surface should be interpreted with a great deal of caution. This does not represent a steady-state or annually averaged surface. As indicated in the literature review section, these water levels were taken during a seasonally low recharge period. The water levels are probably seasonally low and in some places the upper silty unit may be unsaturated.

Furthermore, because of the extremely low permeability of parts of the shallow system, some of the wells may not have reached quasi-equilibrium water levels. The shallow wells are screened at different elevations. Although there is no apparent trend in head changes with depth, this is also another factor that makes interpretation difficult.

With the above limitations considered, some general trends may be discerned. As may be seen, there is a southwesterly gradient. Superimposed on this is a possible groundwater mound at the north end of the canal and a slight depression at the south end of the canal. In most locations, the heads are nearly equal to those in the dolomite. The heads in the shallow system are probably controlled by local variations in permeability, in recharge, and in evapotranspiration and discharge to the creeks and river. The mound is most likely a result of some combination of these factors. However, one set of water-level measurements for one time is insufficient to determine a unique combination.

SECTION 6.0 LOCKPORT DOLOMITE MODEL

6.1 NUMERICAL MODEL

6.1.1 General Information

A numerical model is most appropriate for general problems involving aquifers having irregular boundaries, heterogeneities, or highly variable pumping and recharge rates. For these problems, simplified analytical models no longer describe the physics of the situation, and the partial differential equation describing flow is approximated numerically, for example, with finite-difference techniques. In so doing, one replaces continuous variables with discrete variables that are defined at grid blocks (or nodes). Therefore, the continuous differential equation, defining hydraulic head everywhere in an aquifer, is replaced by a finite number of algebraic equations that defines hydraulic head at specific points. This system of algebraic equations is generally solved using matrix techniques. Thus, the model computes hydraulic heads as they change with time throughout an aquifer in response to applied hydrologic stresses. This approach constitutes a numerical model, and generally, a computer program is written to solve the equations on a digital computer.

There are several numerical models that are appropriate for simulating flow in the Lockport Dolomite. One approach is to vertically average the flow and aquifer parameters through the aquifer thickness. The boundary condition at the bottom is probably no-flow, since below the first 15 feet, parts of the Lockport Dolomite are relatively impermeable. Also, the Rochester Shale is impermeable. At the top, the boundary condition is probably head-controlled flux to represent leakage through the confining bed. A ground-water flow model that handles these areal flow conditions is the U.S. Geological Survey model presented by Trescott, et al. (1976). In addition, this model has been thoroughly tested and is well documented.

The following partial differential equation for ground-water flow in a confined aquifer in two dimensions, developed and discussed in Pinder and Bredehoeft (1968), is in Trescott, et al. (1976):

$$\frac{\partial}{\partial x}\left(T_{xx}\frac{\partial h}{\partial x}\right) + \frac{\partial}{\partial y}\left(T_{yy}\frac{\partial h}{\partial y}\right) = S\frac{\partial h}{\partial t} + W(x,y,t) \qquad (6.1)$$

where

T_{xx}, T_{yy} are the principle components of the transmissivity tensor (L^2/T);

h is the hydraulic head in the aquifer (L);

t is time (T);

S is the storage coefficient (dimensionless); and

W(x,y,t) is the volumetric flux per unit surface area (L/T).

In equation (6.1), it is assumed that the coordinate axes x and y are co-linear with the principal components of the transmissivity tensor, T_{xx} and T_{yy}.

Equation (6.1) is solved by finite-difference methods in the simulation model by Trescott, et al. (1976). In this model, the source term W(x,y,t) can include well discharge or recharge, transient leakage from a confining bed and steady leakage through a confining bed, recharge from precipitation, and evapotranspiration.

To solve equation (6.1) for a heterogeneous aquifer with irregular boundaries, the continuous derivatives are replaced by finite-difference approximations for the derivatives at the node in the center of a block of aquifer whose properties are assumed to be uniform. The following implicit finite-difference equation is written for each node composing the finite-difference grid:

$$\frac{1}{\Delta x_j} \quad T_{xx(i,j+\frac{1}{2})}\frac{(h_{i,j+1,k}-h_{i,j,k})}{\Delta x_{j+\frac{1}{2}}} - T_{xx(i,j-\frac{1}{2})}\frac{(h_{i,j,k}-h_{i,j-1,k})}{\Delta x_{j-\frac{1}{2}}}$$

$$+ \frac{1}{\Delta y_i} \quad T_{yy(i+\frac{1}{2},j)}\frac{(h_{i+1,j,k}-h_{i,j,k})}{\Delta y_{i+\frac{1}{2}}} - T_{yy(i-\frac{1}{2},j)}\frac{(h_{i,j,k}-h_{i-1,j,k})}{\Delta y_{i-\frac{1}{2}}}$$

$$= \frac{S_{i,j}}{\Delta t}(h_{i,j,k}-h_{i,j,k-1}) + \frac{Q_{w(i,j,k)}}{\Delta x_j \; \Delta y_i} - \frac{K'_{i,j}}{b'_{i,j}}(h_{o(i,j)}-h_{i,j,k}) \qquad (6.2)$$

where

i,j,k are indices of the x-, y-, and time-dimensions, respectively; Δx, Δy, Δt are the increments in the x-, y-, and time-dimensions, respectively; $K'_{i,j}$ and $b'_{i,j}$ are the confining bed hydraulic conductivity and thickness, respectively; and $Q_{w(i,j,k)}$ is the well discharge (L^3/T). Writing equation (6.2) for each node in the region at which the head is unknown results in a system of simultaneous linear equations. The system of equations generated by equation (6.2) is solved directly using D4 or alternating diagonal ordering (Price and Coats, 1974). A discussion of this procedure and its incorporation into the model is given in Larson (1978).

6.1.2 Site-Specific Assumptions

The system we are modeling in this section is assumed to consist of a confined aquifer, the permeable part of the dolomite. It is underlain by relatively impermeable rock and overlain by leaky, but lowly permeable clays and till. It is connected hydrologically through the clays and till to a shallow system composed of silty sand and silt fill. Important assumptions determined in part from the literature review section include:

(1) Ground-water flow and aquifer parameters in the Lockport Dolomite are vertically averaged.

(2) Quasi-steady-state flow is assumed; that is, although there are seasonal variations, the system over an extended period of time does not change hydrologically from some seasonally averaged surface. This assumption is based on the few well hydrographs available in the Niagara Falls area.

(3) The aquifer in the Lockport Dolomite is assumed to be leaky artesian everywhere. Evidence in Johnston (1964) generally supports this assumption.

(4) The aquifer transmissivity near the escarpment is assumed equal to 4.92×10^{-4} ft^2/s. Because of the analysis of pumping tests at the Love Canal site, and because of the higher transmissivity reported by Johnston (1964) near the river, a zone bordering the upper Niagara River was assumed to have a transmissivity of 4.92×10^{-3} ft^2/s. This value is about three times less than that obtained from the aquifer test analysis, yet slightly greater than Johnston's 'best' value. This value was selected because the aquifer test yielded a local value, whereas the lower value used in the model is more representative of a larger area. Thus, transmissivity is assumed isotropic, but nonhomogeneous.

(5) Water moves vertically into or out of the Lockport Dolomite through the confining layer.

(6) The confining bed is assumed to be 25 feet thick and is composed of clay and till.

(7) The confining bed hydraulic conductivity is assumed to be 10^{-8}cm/s (Leonard et al., 1977) or 3.28×10^{-10}ft/s. Because of the better drained soils near the Niagara Escarpment (U.S. Department of Agriculture, 1972), this value was increased in that area to 3.28×10^{-9} ft/s. Confining bed hydraulic conductivity is therefore isotropic, but nonhomogeneous.

(8) There are not enough wells in Johnston (1964) to construct a potentiometric surface for the silty sand and silt fill, that is, the shallow system; wells that are in Johnston (1964) indicate that water levels are approximately 10 feet below land surface; therefore, values determined from a topographic map were used and 10 feet subtracted to produce a shallow system potentiometric surface. In the Love Canal area, this resulted in heads that were 565 feet.

(9) The heads in the shallow system represent an average value and neglect seasonal variations or imposed stresses.

(10) The rock underlying the permeable part of the dolomite is considered impermeable.

(11) The scale of the Lockport Dolomite model is regional.
These assumptions are also summarized in Table 6.1.

The area of interest was subdivided into rectangular blocks composing the finite-difference grid and is shown in Plate 4. The grid consists of 21 columns and 23 rows. Note that the first and last rows and columns contain blocks with zero transmissivity as required by the U.S.G.S. two-dimensional model. The northern boundary is considered no-flow because it is located along the middle of a recharge area, i.e., a ground-water divide. Recharge is through the confining bed. The eastern boundary is approximated as no-flow because it follows a flow line. The southern boundary is treated as constant head and corresponds approximately with the upper Niagara River. The western boundary follows approximately the covered conduits of the pump-storage project and is considered constant head. The head values are indicated on the finite-difference grid. How they were determined is discussed in the next paragraph.

According to PASNY (1965), the headwater at the river intake for the pump-storage project averages an elevation of 563 feet above sea level. The twin water conduits extend generally northerly from the intake to the southwest corner of the reservoir, a distance of about four miles. The canal bottom is approximately 100 feet below land surface, so it is well within the dolomite. The conduits drop 11 feet between their upstream and downstream ends, with backfill averaging greater than 40 feet in thickness. Based on this and the data in Johnston (1964), as stated, the western boundary is treated as constant head with the river block fixed at 563 feet. The block near the reservoir is fixed at an average value of 555 feet. The blocks between vary in an approximate linear fashion between these two values.

Table 6.1 Summary of major assumptions for the Lockport Dolomite model.

Model Assumption	Actual Condition	Comment
porous	fracture media and bedding plane solution	On a regional scale, this assumption is generally valid, especially for ground-water flow.
steady-state flow	quasi-steady-state flow with seasonal variations superimposed	none
vertically-averaged properties	variable permeability in the vertical	For the permeable zone on a regional scale, this assumption is generally valid.
leaky artesian everywhere	leaky artesian, but may have water-table conditions near escarpment	The escarpment is far enough away from the Love Canal site that this assumption should not affect results.
vertical flow through confining bed	uncertain	For the contrast in hydraulic conductivities in the confining bed and dolomite, this assumption is valid.
time-invariant heads in shallow system	heads in the shallow system do change with time on a seasonal basis	For modeling steady-state conditions in the dolomite, this assumption is reasonable, but will perform sensitivity analysis.
impermeable bottom	lowly permeable zones exist among the permeable zones	none

(continued on next page)

Table 6.1 (Continued)

Model Assumption	Actual Condition	Comment
higher transmissivity near upper Niagara River	higher transmissivity from pumping tests near upper Niagara River	none
higher confining bed hydraulic conductivity near escarpment	better drained soils near the escarpment	none
constant head for upper Niagara River	river is probably hydraulically connected to dolomite	none
constant head for covered conduits	uncertain	perform sensitivity analysis
impermeable flow at escarpment	dolomite is absent; cut off by erosion	none
impermeable flow to the east	flow line	a flow line is approximated as no-flow boundary
regional heterogeneous transmissivity	heterogeneous transmissivity	none
isotropic transmissivity	bedding plane controlled permeability with minor vertical fractures; areal anisotropy is probably slight	none

6.2 HISTORY MATCHING

6.2.1 General

To demonstrate that a ground-water model of a flow system is realistic, field observations of the aquifer should be compared to computed values from the model. The objective of this history matching procedure is to minimize differences between the observed data and the computed values.

6.2.2 Steady-State Flow

Calibration of the Lockport Dolomite model consists of matching the steady-state potentiometric surface in Plate 1. For steady-state flow conditions, the storage term in the flow equation (6.1) can be eliminated during model calibration. Also, leakage through the confining bed is considered to be under steady-state conditions.

During steady-state calibration, the aquifer transmissivity, confining bed hydraulic conductivity, and potentiometric surface for the shallow system were adjusted until the computer-generated output compared favorably with the observed potentiometric surface. The final values for these parameters are those given in section 6.1.2. The process of adjusting parameters is a subjective one, and a given combination of parameters that produces an acceptable match is usually not a unique one.

The computed potentiometric surface is shown in Plate 5. As may be seen, the match is good on a regional scale, with the gradient in the Love Canal area being toward the south and southwest. For this simulation, referred to as run 1, flow into and out of the aquifer occurred through the confining bed (leakage) and constant head nodes. Total sources over the entire modeled area consisted of 0.063 ft^3/s from constant head nodes and 0.095 ft^3/s from leakage. Total discharges over the entire modeled area consisted of 0.104 ft^3/s through constant head nodes and 0.052 ft^3/s through leakage. Since the problem is steady state, total sources should equal total sinks, which is the case, within the limits of the rounded numbers. In terms of spatial distribution, leakage into the Lockport occurred near the topographic high in the northern part of the study area. Leakage out occurred toward the escarpment and down gradient toward the upper Niagara River. Just north of the canal, the gradient reversed and leakage was generally into the Lockport down to the upper Niagara River. Thus, in the Love Canal area, the gradient is downward (on an annual average), using the value of 565 feet for the heads in the shallow system at the Love Canal site. The downward flow in the blocks representing the canal area, however, is very low with rates ranging from 5.6×10^{-3} to 2.6×10^{-3}in/yr. The head difference between the dolomite and shallow system is very small, especially near the south end of the canal, and as will be discussed in the sensitivity section, this gradient can easily be reversed. As for constant head nodes, flow was into the dolomite at the pump-storage reservoir and, in general, was out through the western boundary. For the southern boundary, the upper Niagara River was gaining from the dolomite near Love Canal and east; toward the west and near the pump-storage intakes, the upper Niagara River was generally losing to the dolomite.

A cross section through column 11 (see Plate 4) from the escarpment to the upper Niagara River is shown in Figure 6.1. This is compared with the observed hydraulic head from Plate 1. Again, the match is good on a regional scale. On a more local scale, consider Figure 6.2, which compares the hydraulic head computed from run 1 with the measured values from this study; that is, in just the Love Canal area (section A-A' on Plate 4, with observed data from Plate 2). As may be seen, even on a local scale, this match is good with the computed values being slightly lower than the observed. This difference may be the result of the constant head value of 564 feet that was used for the upper Niagara River near Love Canal. As may be seen, the observed line near the river is dashed indicating that limited data were available there. This also indicates our uncertainty in using 564 feet as the constant-head value. The effect of the constant head boundary at the upper Niagara River is discussed in more detail in the section on sensitivity analysis.

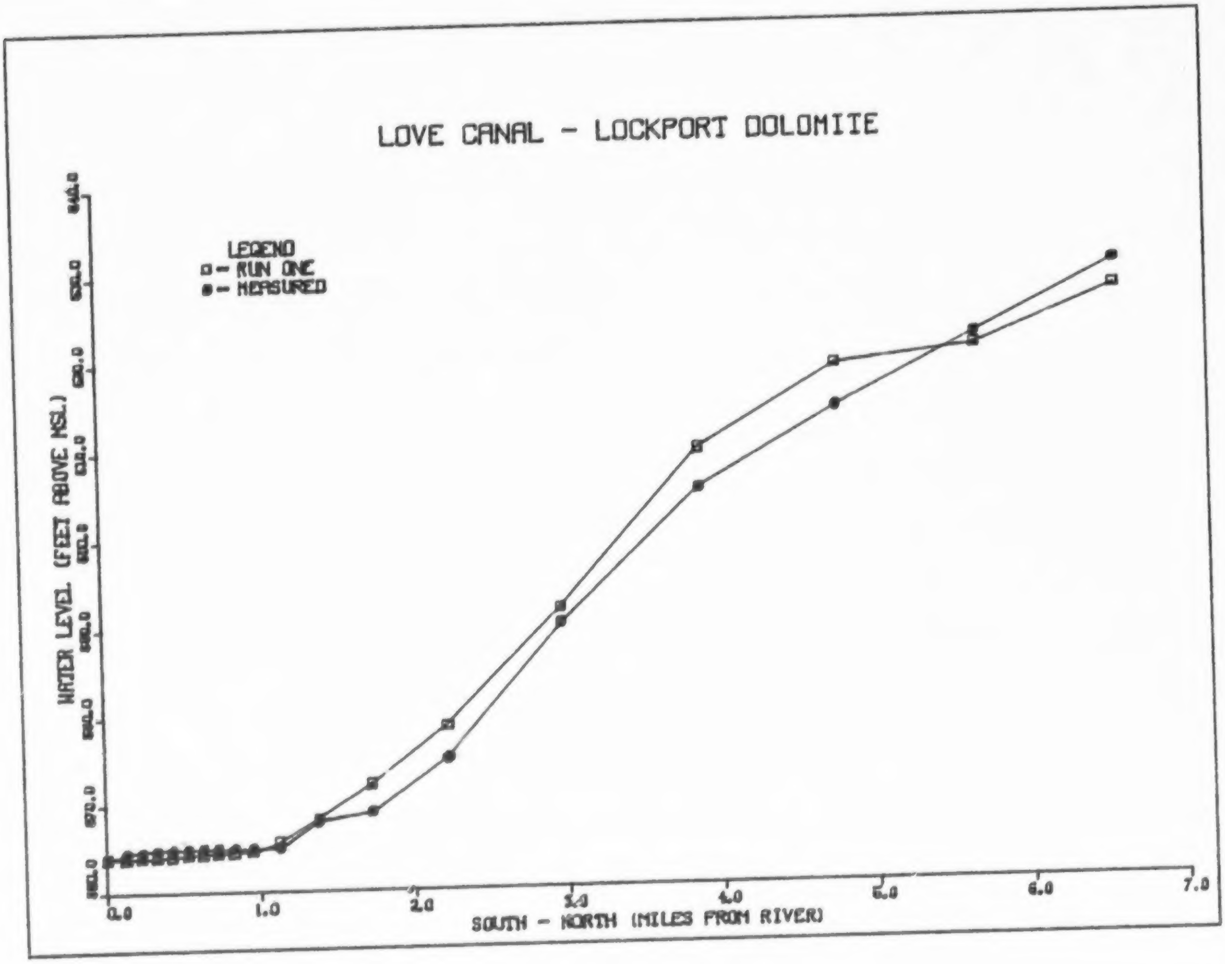


Figure 6.1 Comparison of computed heads from run 1 with measured heads. Section line is through column 11 in Plate 4; river head (origin) is constant at 564 feet.

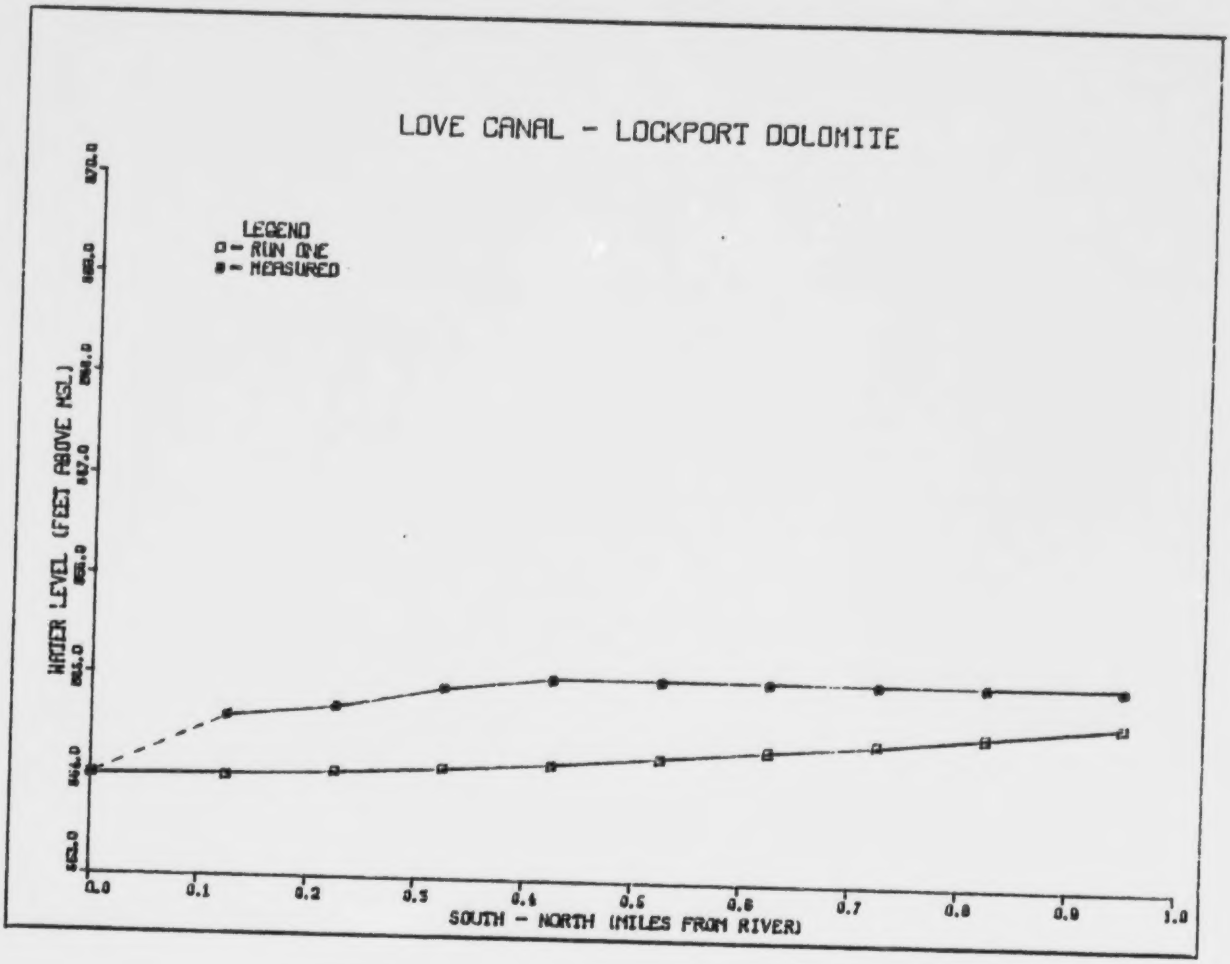


Figure 6.2 Comparison of computed heads from run 1 with measured heads. Section line is A-A' through Love Canal in Plate 4; river head (origin) is constant at 564 feet.

6.3 SENSITIVITY ANALYSIS

6.3.1 General

Sensitivity analysis may be defined as the systematic variation of selected model parameters to investigate the effects on model responses. Given a specific model response of interest, which hydrologic parameters or conditions affect the response most strongly? This is the information that sensitivity analysis provides.

6.3.2 Site Specific

A sensitivity analysis was made on the steady-state model of the Lockport Dolomite. The following were considered:

- the condition at the western boundary
- aquifer transmissivity
- confining bed hydraulic conductivity
- river stage at the southern boundary
- water level in the shallow system

The western boundary of the modeled area was assumed to be the pump-storage reservoir and the covered conduits. Based on the description of these engineered structures and on data in Johnston (1964), this boundary was treated as constant head, with the heads varying spatially according to the observed data. Because this boundary is outside the Love Canal area, no data were collected near it during the current study. There is, therefore, uncertainty in our treatment of this boundary as constant head. To test the effect of the constant head boundary condition, a sensitivity simulation was made treating the western boundary as impermeable. This simulation is called run 2. The main change in the computed hydraulic heads occurred near the western boundary, where the hydraulic gradient was reduced. Figure 6.3 shows the effect of this change on the hydraulic heads in the Love Canal area. This is the same section shown in Figure 6.2; that is, section A-A' in Plate 4. As may be seen by comparing runs 1 and 2, changing the condition at the western boundary caused little change in the hydraulic heads in the Love Canal area. Based on this sensitivity run, the model appeared insensitive to this boundary condition, and the constant head boundary condition was used.

Next the sensitivity of the model to changes in transmissivity was tested. In run 3, the aquifer transmissivity was increased 50% to 7.38×10^{-4} and 7.38×10^{-3} ft^2/s in the respective areas. In run 4, the transmissivity was decreased 50% to 2.46×10^{-4} and 2.46×10^{-3} ft^2/s in the respective areas. The results of these simulations are compared to run 1 in Figure 6.4. As may be seen, increasing transmissivity caused the heads to increase in the Love Canal area, and decreasing the transmissivity caused the heads to decrease. The maximum change occurred toward the north end of the Love Canal area, and was only 0.3 feet for run 4. An increase in transmissivity allows more flow from the north causing an increase in heads in the Love Canal area

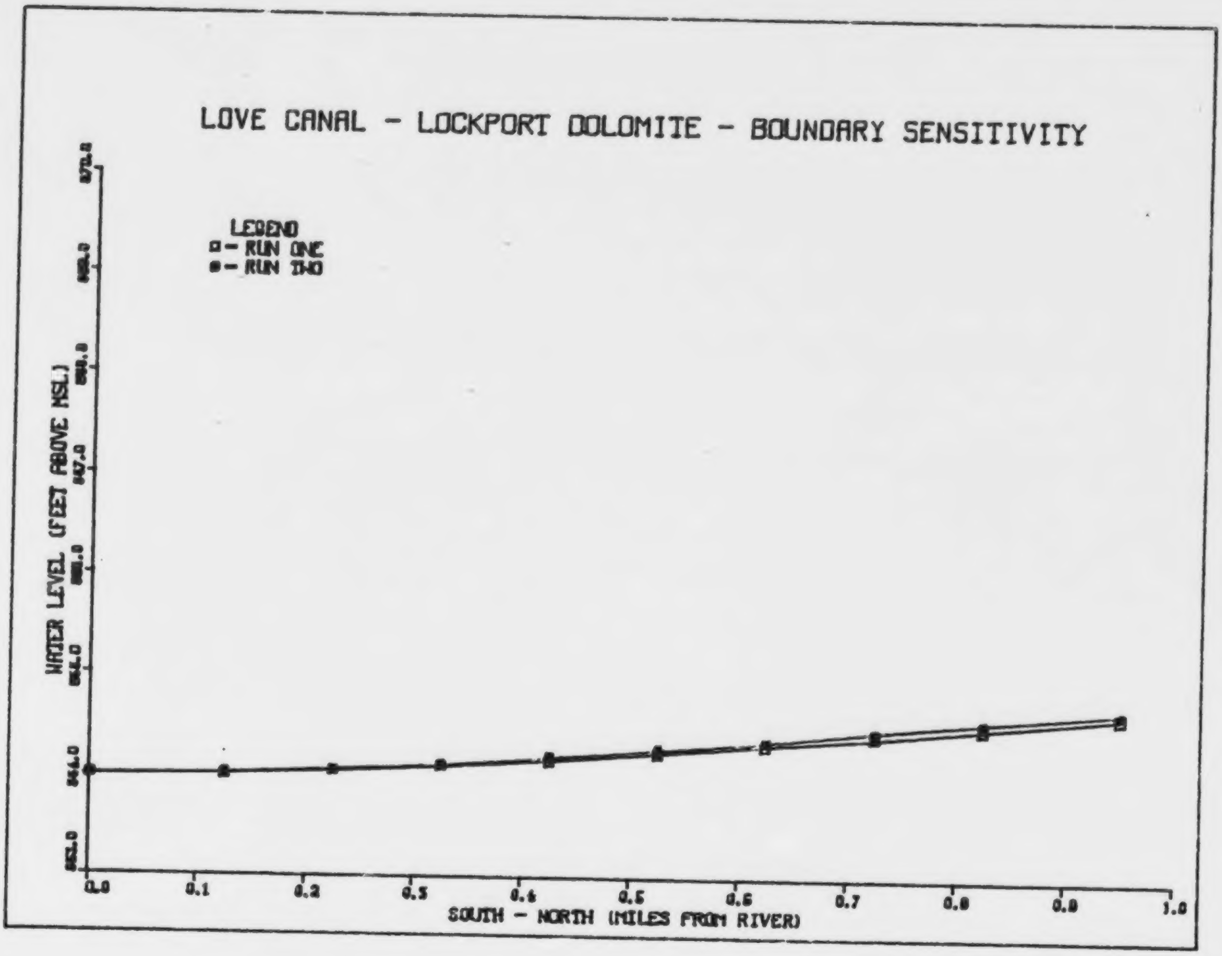


Figure 6.3 Comparison of computed heads from runs 1 and 2. Section line is A-A' through Love Canal in Plate 4; river head (origin) is constant at 564 feet. Run 2 - impermeable boundary toward west.

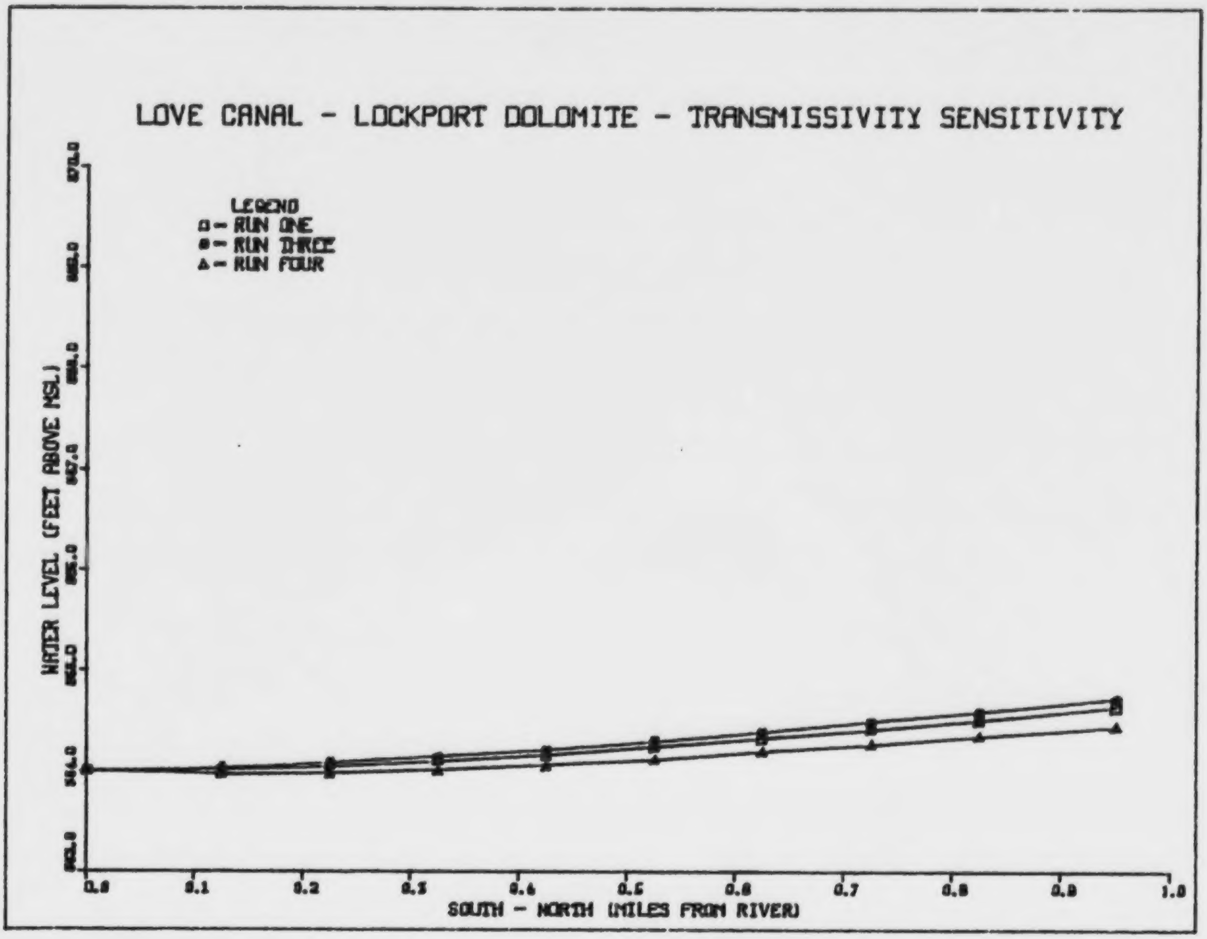


Figure 6.4 Comparison of computed heads from runs 1, 3, and 4. Section line is A-A' through Love Canal in Plate 4; river head (origin) is constant at 564 feet. Run 3 - high transmissivity; run 4 - low transmissivity.

and a decrease in head in the northern part of the modeled area (not shown in Figure 6.4). Since the river is held constant at 564 feet, there is little effect on the heads near the south end of Love Canal. Based on these runs, the system, as modeled, is relatively insensitive to these changes in transmissivity.

For runs 5 and 6, the confining bed hydraulic conductivity was increased and decreased by 50%, respectively. This resulted in hydraulic conductivities of 4.92×10^{-10} and 4.92×10^{-9} ft/s for run 5, and 1.64×10^{-10} and 1.64×10^{-9} ft/x for run 6. These are compared to run 1 for the Love Canal area in Figure 6.5. Results are similar to those in Figure 6.4, except that an increase in confining bed hydraulic conductivity produced a decrease in hydraulic head in the Love Canal area and an increase in the northern part of the modeled area (not shown in Figure 6.5). All changes are very slight indicating that the model is relatively insensitive to changes in confining bed hydraulic conductivity of the magnitude discussed.

Although the confining bed thickness was not varied, for steady-state flow conditions, the ratio of K'/b' (referred to as leakance) controls leakage. Therefore, by varying the hydraulic conductivity, K', we have varied this ratio. We could have varied confining bed thickness, b', inversely to the way we varied K' and obtained the same

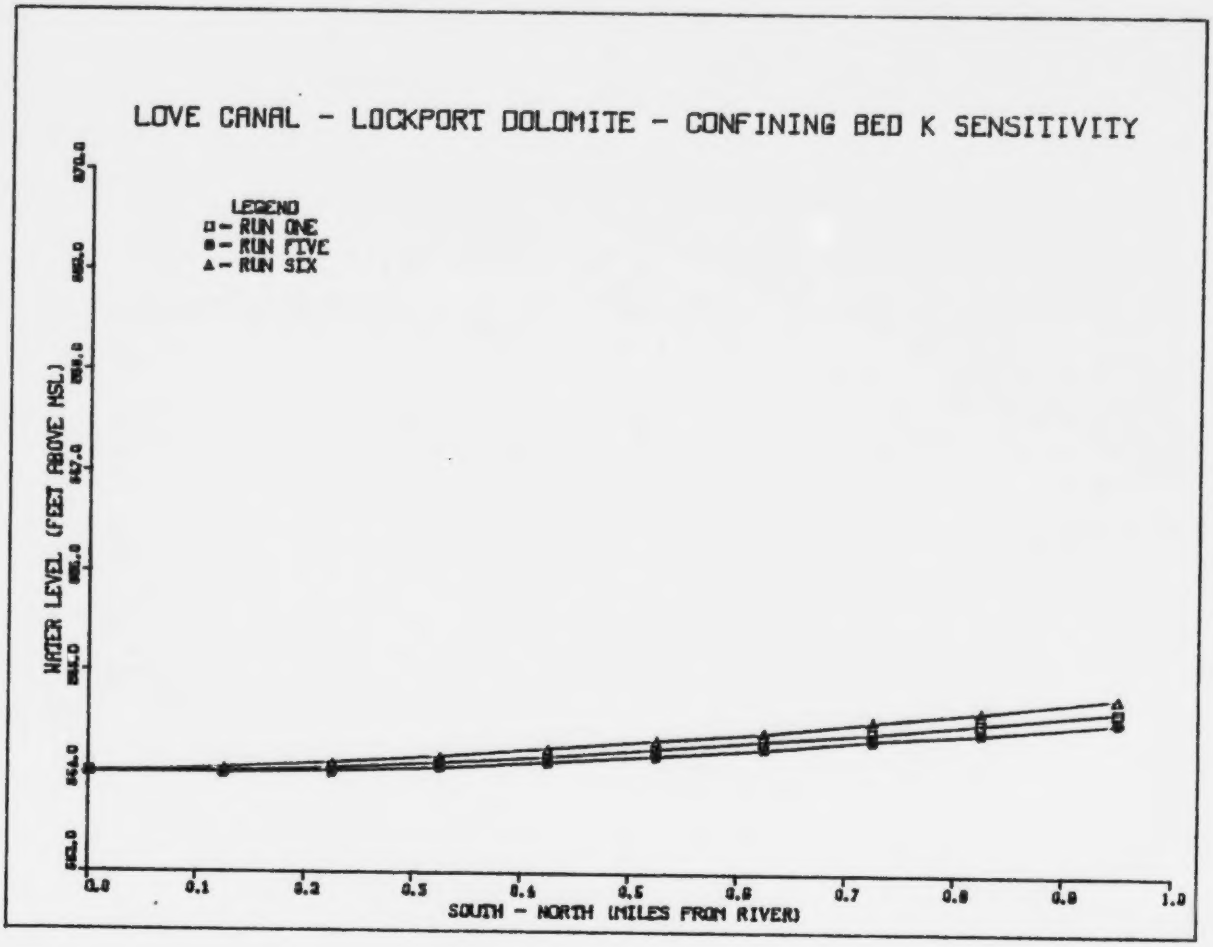


Figure 6.5 Comparison of computed heads from runs 1, 5, and 6. Section line is A-A' through Love Canal in Plate 4; river head (origin) is constant at 564 feet. Run 5 - high confining bed K; Run 6 - low confining bed K.

results for computed hydraulic head.

Other sensitivity runs on the dolomite model were made by changing the stage of the upper Niagara River. In run 7 the stage was increased by one foot to 565 feet, whereas in run 8, the river elevation was decreased a foot to 563 feet. Results are compared in Figure 6.6 with those from run 1. As may be seen, these runs caused the most change in the hydraulic heads in the Love Canal area. The value used in run 1 for the constant head nodes near the upper Niagara River may be inappropriate. By comparing Figures 6.2 and 6.6, it may be seen that by increasing the constant head value by approximately 0.5 ft, the match between the calculated and observed heads would be very close.

Note that the lines in Figure 6.6 represent new steady-state locations, and that all three gradients are toward the river. As will be seen in the prediction section, system parameters are such that the dolomite would reequilibrate to a new steady state relatively quickly. Therefore, although an increase in river stage would cause an initial gradient away from the river into the dolomite, as the steady-state position were reached, the gradient would reverse and would end as shown, with the gradient toward the river.

Additional sensitivity runs were made, however, no figures are presented. In the first run, run 9, the hydraulic head in the shallow system was lowered by one foot in the Love Canal area. This produced a reversal in the direction

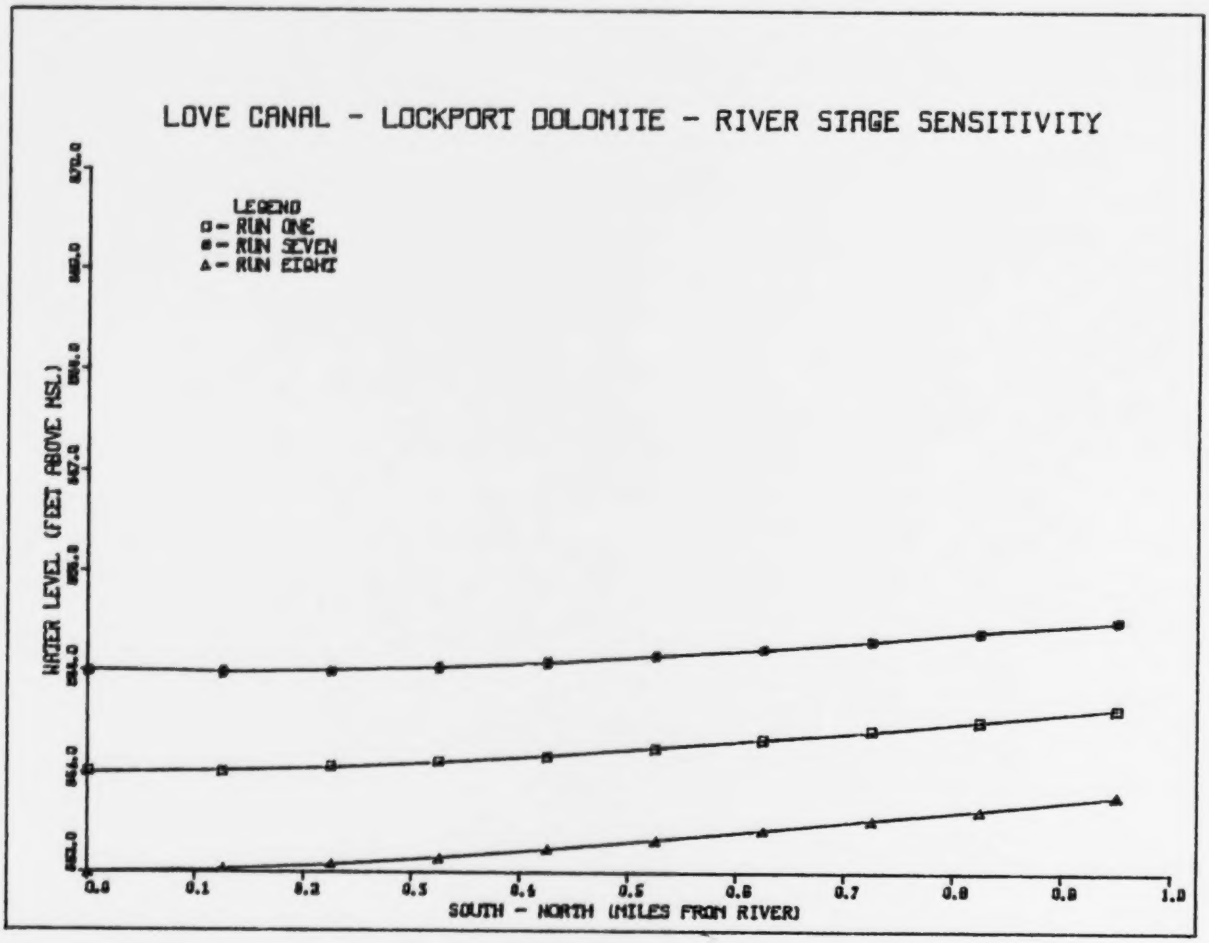


Figure 6.6 Comparison of computed heads from runs 1, 7, and 8. Section line is A-A' through Love Canal in Plate 4; river heads are fixed at 563, 564, and 565 feet.

of flow through the confining bed; that is, flow was out of the Lockport Dolomite. The heads in the two systems (shallow and dolomite) are nearly equal, and it is possible that local gradients can be in either direction. In addition, as the heads fluctuate seasonally, the gradient may reverse. In either case, because of the low permeability of the confining bed, the vertical rates are small, assuming the confining bed is present everywhere.

In the final sensitivity simulation, run 10, it was assumed that the confining bed was breached. This was simulated in the model by assigning the grid block (17,11), representing the south end of the canal, a confining bed hydraulic conductivity equal to that in the aquifer, that is 3.28×10^{-4} ft/s. For this run, the heads in the dolomite were increased, since the breached area acted as a source. In effect, a ground-water high was produced around grid block (17,11), with this block having a head equal to that in the shallow system, 565 feet. This is partly the result of holding the shallow system head constant. In the field, there would be a cone of depression in the shallow system overlying the mound in the dolomite. Since the hydraulic heads in the two systems are nearly equal, it is not possible, based on hydrologic evidence alone, to determine whether the confining bed was breached.

The sensitivity runs are summarized in Table 6.2. The modeled area, especially in the vicinity of Love Canal, appears to be most sensitive to the stage of the upper Niagara River. In all sensitivity runs, the gradient is generally toward the upper Niagara River, so that any solute that entered the Lockport Dolomite would flow toward the south and southwest.

6.4 PREDICTIONS ASSUMING REMEDIAL ACTION

Under natural conditions, flow in the Lockport Dolomite appears to be at steady state. If remedial action for the dolomite is deemed necessary at some point in the future, the flow field will undoubtedly be disrupted. This will cause transient flow in the dolomite, which can also be simulated.

The steady-state model described in the previous section was modified by reading in values for the confining bed specific storage and the aquifer storage coefficient. For the storage coefficient, a value of 1.5×10^{-4} was used as determined from the pumping test analysis (see section 4.3). A value of 7.8×10^{-4} ft^{-1} was estimated for the specific storage from Domenico (1972, p. 231). This is the value given for a plastic to stiff clay. In addition to the parameters, the steady-state hydraulic head distribution was used as the initial conditions in the transient model.

Table 6.2 Summary of sensitivity runs for dolomite.

RUN	DESCRIPTION	EFFECT
1	Lockport Dolomite steady state using constant head boundary toward the west and best estimate of parameters	'Best' comparison with observed data
2	Same as run 1 except with impermeable boundary toward the west	Minor changes in heads at Love Canal site
3	Same as run 1 with aquifer transmissivity increased 50%	Slight increase in heads at Love Canal site
4	Same as run 1 with confining bed hydraulic conductivity increased by 50%	Slight decrease in heads at Love Canal site
5	Same as run 1 with confining bed hydraulic conductivity increased by 50%	Slight decrease in heads at Love Canal site
6	Same as run 1 with confining bed hydraulic conductivity increased by 50%	Slight increase in heads at Love Canal site
7	Same as run 1 with river stage increased one foot	About one foot increase in heads at Love Canal site
8	Same as run 1 with river stage decreased one foot	About one foot decrease in heads at Love Canal site
9	Same as run 1 with heads in the shallow system in the Love Canal area lowered by one foot	Gradients through the confining bed were reversed; flow was out of the dolomite
10	Same as run 1 with confining bed hydraulic conductivity increased to that of the dolomite in the grid block representing the south end of Love Canal	Created ground-water mound in the dolomite

Remedial action, if necessary, will probably consist of intercept wells in the dolomite. To test the effectiveness of intercept wells, sinks were incorporated into the Lockport Dolomite model at the south end of Love Canal. That is, pumping well blocks were placed in blocks (18,10), (18,11) and (18,12) in the finite-difference grid in Plate 4. These were placed at the southwest, south, and southeast end of the canal, since the flow gradient in the Lockport Dolomite is toward the south and southwest; therefore, wells in this location would intercept any solute that entered the dolomite from the canal.

The pumping rates of the three well blocks were each 2.0 gal/min. This amounts to a total of 6 gal/min or 8640 gal/day. The treatment facility at Love Canal should be able to handle this additional amount of liquid.

The transient simulation lasted only about 6.7 days, after which time, the hydraulic heads in the dolomite came to a new steady state. The results of this simulation after 6.7 days are shown in Figure 6.7. As may be seen, these low pumpages are sufficient to cause a reversal in the hydraulic head gradient. That is, the flow is no longer toward the upper Niagara River, which means the wells would successfully intercept flow from under the canal in the dolomite. Although the grid block heads are plotted in Figure 6.7, the maximum drawdown computed at the well face

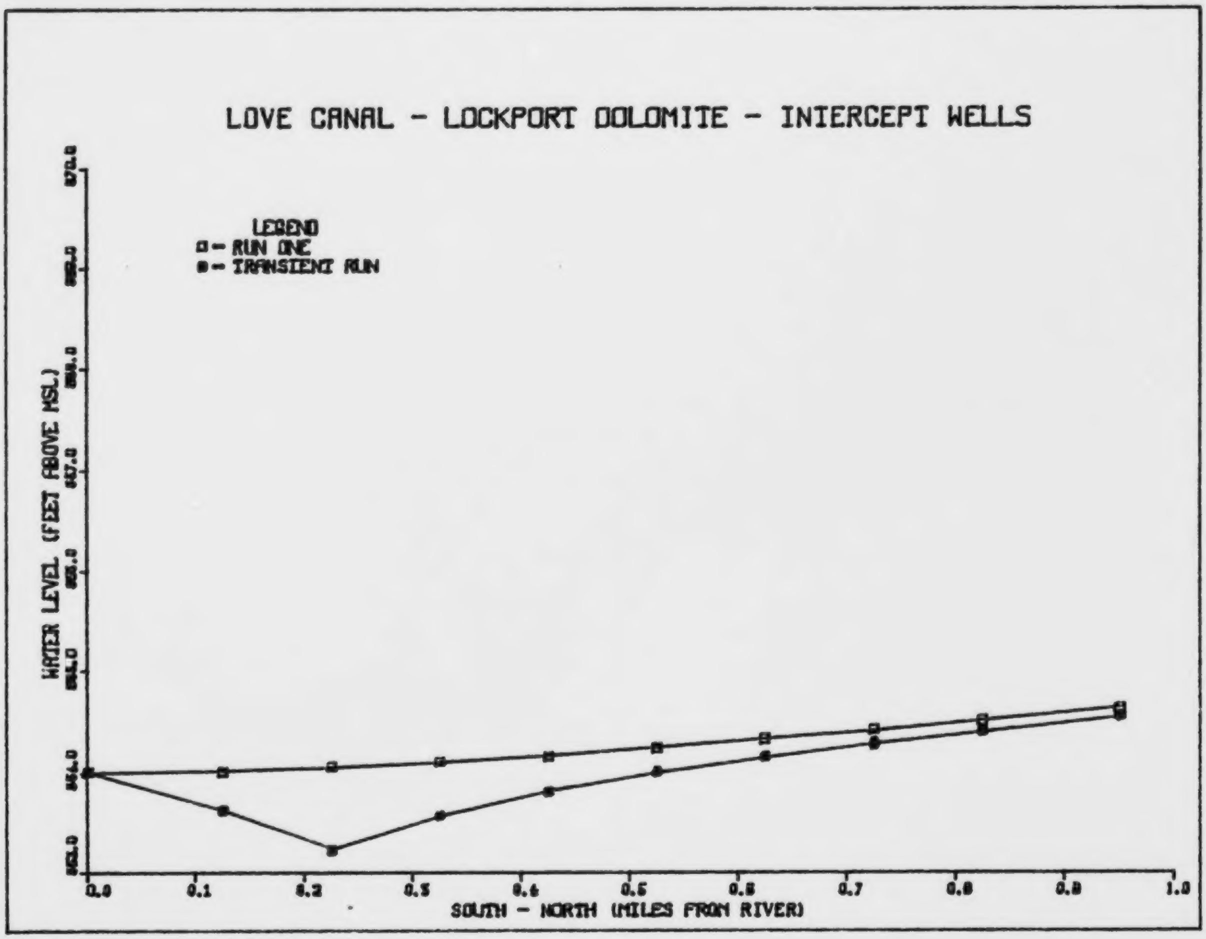


Figure 6.7 Comparison of computed heads from run 1 and the transient simulation. Section line is A-A' through Love Canal in Plate 4; river head (origin) is constant at 564 feet.

(assuming a well radius of 0.25 feet) would be approximately 2.7 feet, so that the assumption of confined, artesian conditions in the dolomite are still valid.

This new steady-state solution is dependent on the assumption of a constant head boundary to represent the upper Niagara River. The hydraulic connection of the river and the Lockport Dolomite is uncertain. If the connection is less than direct as treated in the model, then the gradient would still be reversed by this pumpage; however, steady state may not be reached as quickly.

6.5 TRAVEL TIMES AND UNCERTAINTY ANALYSIS

6.5.1 Lockport Dolomite

In this section, we assume that solute has entered the Lockport Dolomite, and using the gradient and other hydraulic parameters from the history-matching section, travel times are computed for the solute to reach the upper Niagara River. The travel times vary depending on the assumptions of the hydraulic properties of the dolomite and the behavior of solute.

The interstitial velocity of flowing ground water can be written

$$v_i = \frac{K}{\phi} \frac{\partial h}{\partial s}$$

where v_i = interstitial velocity (ft/s)

K = hydraulic conductivity (ft/s)

ϕ = porosity (dimensionless), and

$\frac{\partial h}{\partial s}$ = hydraulic gradient (dimensionless).

Travel time, t(s), is simply distance, L(ft), divided by interstitial velocity, v_i. The amount of solute present on the rock is assumed to be directly proportional to the amount of solute present in the fluid. This proportionality constant is called the distribution coefficient, k_d (ml/gm), and from it one can calculate the rate of movement of solute in a flowing ground-water system relative to the rate of flow of the transporting water itself according to the expression

$$\frac{\text{water velocity}}{\text{solute velocity}} = (1 + \frac{\rho}{\phi} k_d)$$

where

ρ = aquifer bulk density and ϕ = effective porosity.

Adjusting velocities and travel times for this retardation effect results in a complete expression for solute travel times

$$t = \frac{L\phi}{K(\frac{\partial h}{\partial s})} (1 + \frac{\rho}{\phi} k_d) \qquad (6.3)$$

Although this is a relatively simple equation, there are considerable uncertainties associated with ϕ, K, and k_d, which lead to uncertainties in the resulting calculated travel times. In this section, best estimated travel times for solute with various sorption properties to reach surface water are calculated. These calculations are made without any regard to the scenario by which the solute entered the groundwater system. The uncertainty of this estimate is evaluated using Monte Carlo simulation techniques.

The following best estimates are selected for evaluating equation (6.3)

L = 660 feet, distance from the south end of Love Canal to the river

K = 0.001 ft/s (from pumping test match, that is, 0.015 $\text{ft}^2/\text{s} \div 15$ ft, where a permeable thickness of 15 feet is assumed)

$\frac{\partial h}{\partial s} = \frac{0.1}{660} = 0.000152$ (from measured hydraulic head)

ρ = 2.5 gm/ml, common limestone density (Clark, 1966)

ϕ = 0.02, effective porosity (estimated for fractured limestone from Winograd and Thordarson, 1975)

k_d = 0 to 10 ml/gm (estimated from Apps, et al., 1979).

These values are best estimates from observed data, the pumping test simulation, and our judgment. The major assumptions are also summarized in Table 6.3. With them, equation (6.3) gives a travel time for a perfect tracer ($k_d = 0$) or for the water itself of 1,005 days. That is, if the clays were breached or if solute were transported through the clays, upon entering the Lockport Dolomite, it would take 1,005 days to reach the river.

In order to assess the statistical properties in the predicted results, it is first necessary to specify the statistical properties of the uncertain parameters. In

Table 6.3 Summary of major assumptions for the Monte Carlo model.

Model Assumption	Actual Condition	Comment
porous media	fractured media	the effect of this assumption on travel times is accounted for in the uncertainty analysis
flow length is from south end of canal to river	direction of flow is toward south	none
uniform gradient	low, fairly uniform gradient	none
low effective porosity	unknown	fracture porosity are generally low; the uncertainty of this assumption is accounted for in this analysis
only chemical reaction is adsorption	unknown	this probably has the major effect on travel times
local hydraulic conductivity	hydraulic conductivity from pump tests	local travel times; the uncertainty of this assumption is accounted for in this analysis
aquifer thickness is 15 feet	unknown	this factor enters into the determination of K from T/b; the uncertainty in b is thus incorporated into the uncertainty in K

this case the parameters in (6.3) which have the greatest uncertainty are the hydraulic conductivity, the porosity, and the distribution coefficient. In the analysis that follows, we will assume statistical properties for ϕ and K. To evaluate the uncertainty in k_d, we will perform a sensitivity analysis.

Freeze (1975) presents a large body of both direct and indirect evidence that provides support for a log normal frequency distribution for hydraulic conductivity. If it is assumed that hydraulic conductivity is log normally distributed, a new parameter y = log K can be defined that is normally distributed and can be described by a mean value, μ_y, and a standard deviation, σ_y, that is,

$$N \left[\mu_y, \sigma_y\right]$$

For this application, $\mu_y = 1.9365$ and $\sigma_y = 0.5$, that is,

$$K = 10^{(1.9365 \pm 0.5)} \text{ ft/day},$$

which is approximately the value obtained from the pumping test match, with the standard deviation assumed to be one-half log unit. Freeze (1975) gives a range of hydraulic conductivity data for fractured rock with standard deviations ranging from 0.20 to 1.56, with a mean of 0.6785. These values of standard deviations indicate a larger spread of values for hydraulic conductivity than that shown in Table 4.2. Because the values in Freeze (1975) are more comprehensive, our value of one-half log unit was estimated from his data.

We use feet per day to compute travel times in terms of days.

For the first simulation, case 1, we estimated porosity to be 2 percent, that is $\phi = 0.02$. Although in theory, a value for porosity may be calculated from the storage coefficient obtained in the aquifer testing section, in this case, it was not possible. The storage coefficient determined from the aquifer test indicates that the aquifer compressibility is more important than the water compressibility. Consequently, the storage coefficient is relatively insensitive to porosity and the porosity could not be determined. Values of K were chosen from a log normal probability distribution. This was done by recognizing that the values of $y_i = \log K_i$ come from a normal probability distribution. The normal generator is

$$y = \sigma_y S_n + \mu_y \tag{6.4}$$

where S_n is a random number taken from a normal distribution with a zero mean and a standard deviation of one, $N[0,1]$. To obtain S_n, we use a random number, R_n^*, uniformly distributed on the interval (0,1). R_n^* is used to compute S_n (also called the random normal deviate) by

$$S_n = (-2 \ln R_n^*)^{\frac{1}{2}} \sin 2\pi R_{n+1}^* \tag{6.5}$$

(see Ralston and Wilf, 1967). Using the value of y from equation (6.4), hydraulic conductivity is computed from

$$K = 10^y$$

and used in equation (6.3) to compute the travel time to the upper Niagara River. To check convergence, we ran the Monte Carlo simulations for 3200 and 6400 events. No significant difference appeared to exist and the 6400 event distribution was used.

A plot of the fraction of events in each interval versus the logarithm of travel time for a perfect tracer ($k_d = 0$) is shown in Figure 6.8. Case 1 refers to the case where the 'best estimate' for porosity is used. Note that if porosity were decreased by an order of magnitude, the plot would shift one log unit to the left.

The spread of the plotted travel times reflects the confidence with which we are able to specify them, given the precision of our estimate of the hydraulic conductivity, K. A range of 2σ on each side of the mean encompasses the 95% confidence interval. Based on the tabulated mean and standard deviation in Table 6.4, this means that there is a probability of less than 0.05 that the travel time of a tracer (non-retarded element) will be greater than 9727 days ($10^{3+2*0.494}$) or less than 103 days ($10^{3-2*0.494}$).

In the next case, 2, we try to account for the uncertainty in both hydraulic conductivity and porosity, but assume they are uncorrelated. We keep the same log normal distribution for hydraulic conductivity, but now assume that porosity is

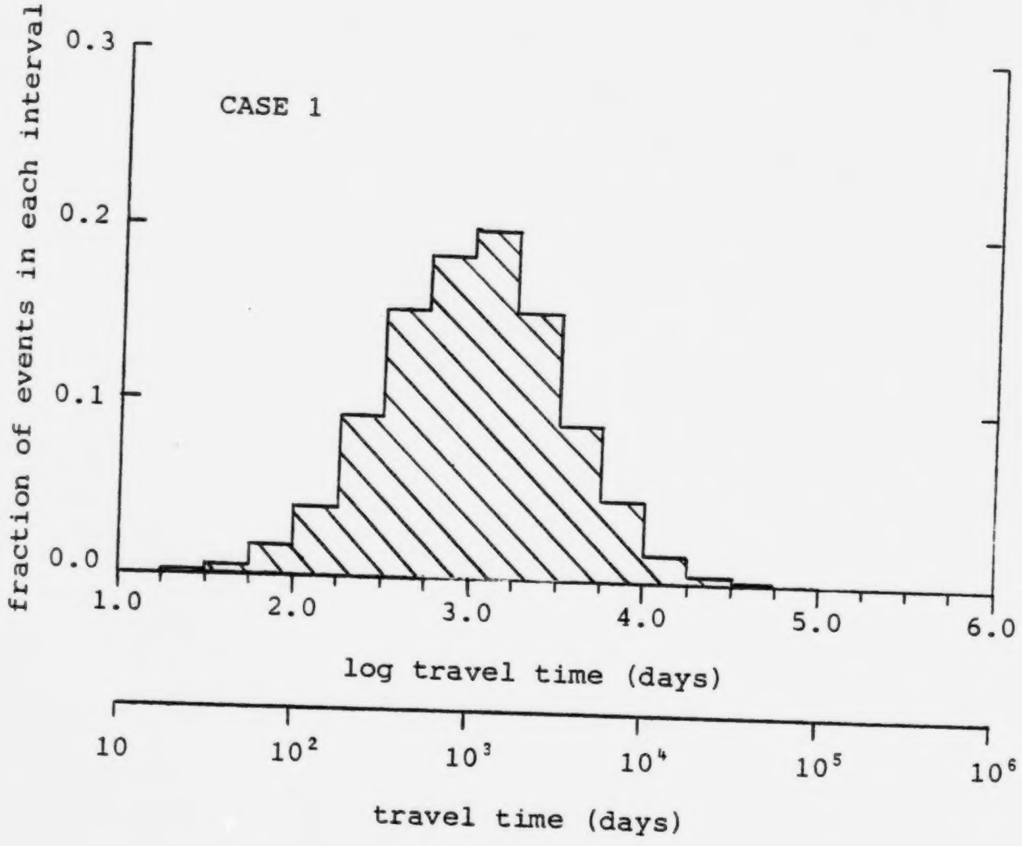


Figure 6.8 Histogram of travel times in days of solute from the south end of Love Canal to the upper Niagara River through the Lockport Dolomite. Values are computed by Monte Carlo simulation for known porosity, uncertain hydraulic conductivity and a distribution coefficient of zero.

also log normally distributed with a standard deviation of 0.5 log units. That is, $x = \log \phi$ where $N\left[\mu_x, \sigma_x\right]$ and $\mu_x = -1.70$ and $\sigma_x = 0.5$. This corresponds to a mean porosity of 0.02. The values of porosity are thus chosen from a log normal probability distribution which is done by recognizing that the values of $x_i = \log \phi_i$ come from a normal probability

Table 6.4 Value of log mean and log standard deviation of travel times in days of solute from the south end of Love Canal to the upper Niagara River through the Lockport Dolomite for several values of distribution coefficients and varying uncertainty assumptions about hydrologic parameters.

Distribution Coefficient k_d (ml/gm)	0.0		1.0		10.0	
	Mean	Sigma	Mean	Sigma	Mean	Sigma
CASE 1	3.00	0.494	5.11	0.507	6.11	0.504
CASE 2	3.00	0.719	5.10	0.502	6.10	0.500

$$x = \sigma_x S_{n+1} + \mu_x$$

where S_{n+1} is a random number taken from $N\left[0,1\right]$. S_{n+1} is determined from Ralston and Wilf (1967) as

$$S_{n+1} = (-2 \ln R^*_n)^{\frac{1}{2}} \cos 2\pi R^*_{n+1} \qquad (6.6)$$

Equations (6.5) and (6.6) provide a corresponding pair of random normal deviates with zero mean and unit variance for R^*_n and R^*_{n+1}.

Monte Carlo simulations for case 2 produce the results shown in Figure 6.9. For case 2, the most probable travel time again is 3.00 log days, but the standard deviation in log units now is 0.719. For this case, the probability is less than 0.05 that the travel time of a tracer will be greater than 27,416 days or less than 38 days. This broad spread in travel times in case 2 ($\sigma = 10^{0.719}$) is a result of our assumption that porosity and hydraulic conductivity are completely uncorrelated. There is unquestionably some correlation between porosity and conductivity at Love Canal, as there is everywhere. However, the amount of correlation is unknown, as is, therefore, whether the appropriate travel time standard deviation is closer to $10^{0.494}$ or to $10^{0.719}$. We will assume that the travel time standard deviation is adequately represented by that resulting from uncertainty in the conductivity alone, $10^{0.949}$, as for case 1.

The preceding discussion and the results displayed in Figure 6.8 and 6.9 were restricted to solutes that are not

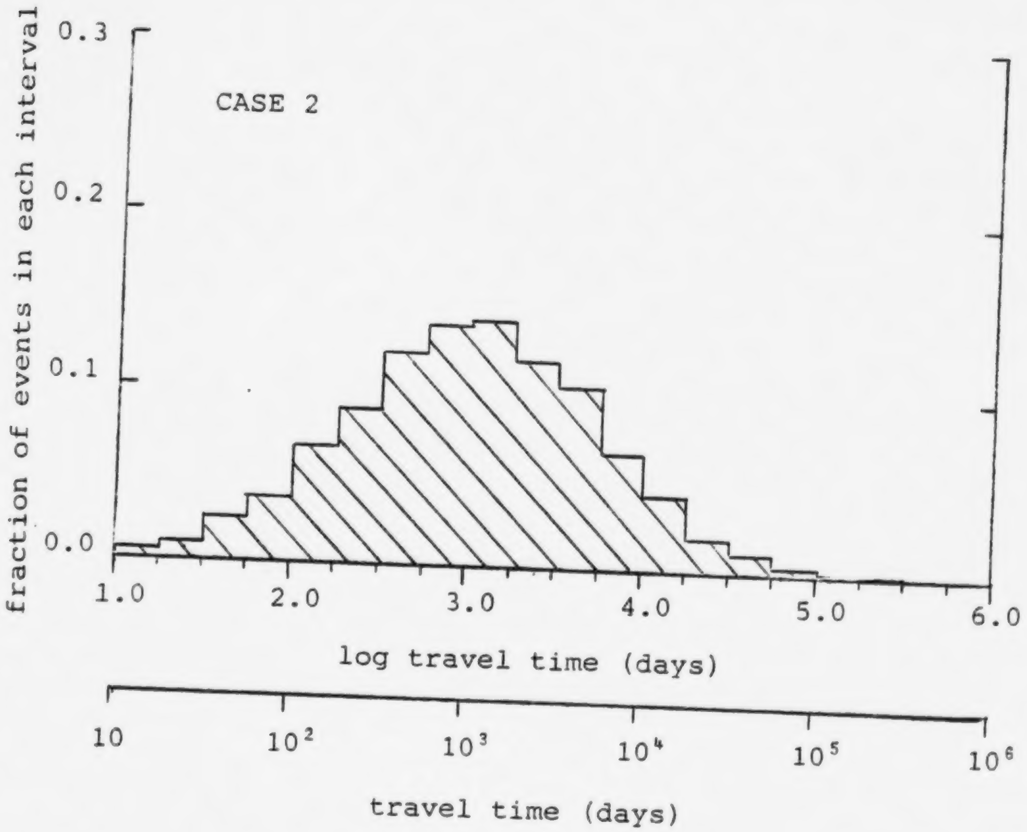


Figure 6.9 Histogram of travel times in days of solute from the south end of Love Canal to the upper Niagara River through the Lockport Dolomite. Values are computed by Monte Carlo simulation for uncertain and independent hydraulic conductivity and porosity.

retarded; that is, to tracers. Such solutes have k_d values of zero, so that the parenthetic expression within equation (6.3) equals one. Many of the solutes at Love Canal are likely to be retarded with non-zero k_d values.

To account for retardation, additional sets of Monte Carlo simulations were made using equation (6.3) and fixed k_d values of 1.0 and 10.0. Two runs were made for each k_d value, corresponding to the conductivity and porosity choices of the two cases described above. The results are given in the form of tabulated log means and standard deviations of travel time in Table 6.4.

The mean values of Table 6.4 show how retardation increases travel time from mean values of $10^{3.00}$ (1000 days) for a tracer to $10^{6.11}$ (1,288,250 days) for a solute with a $k_d = 10$. Of particular interest, though, is that the standard deviation associated with all retarded travel times are the same and approximately equal to $10^{0.5}$.

The Monte Carlo calculations confirm what could have been deduced from consideration of equation (6.3). The difference between cases 1 and 2 that lead to the different standard deviations of tracer travel times result from different assumptions about the uncertainty associated with the porosity estimates. In equation (6.3), when k_d is non-zero, porosity is important in the denominator of the parenthetic term, as well as in the numerator of the other part of the equation. The uncertainties in the porosity values therefore tend to cancel, leaving as the residual travel time uncertainty only the input standard deviation associated with the conductivity estimate. This is 0.5 log units, the value produced by the Monte Carlo calculations.

6.5.2 Confining Bed

The travel times from the bottom of the canal through the confining bed to the Lockport Dolomite are also of interest. In the calibration of the dolomite model, run 1, the leakage rate for a typical block representing the canal was approximately 3.5 x 10^{-12} ft/s. This value can be used as a basis for estimating travel times through the confining bed by using the formula

$$t = \frac{b'\phi'}{q_z}$$

where b' is the thickness of the confining bed below the canal, ϕ' is the confining bed porosity, and q_z is the leakage rate given above.

If it is assumed that the confining bed was not breached during excavation of the canal, then there are two extreme possibilities for flow through the confining bed. In the first case, we assume a thickness of 10 feet for the confining material. This is less than the 25 feet used in the dolomite model; however, because we are concerned with directly under the canal, it is anticipated that the thickness of the confining bed has been reduced somewhat by excavation. In addition, we assume that the confining bed has an effective porosity of 0.1. Since we do not know what the effective porosity actually is, the effect of this parameter on the travel time will be demonstrated in the next case. Using these values and the above formula, the travel time for a tracer to reach the dolomite would be about 9,000 years.

Although travel times on the order of thousands of years are highly likely, a possibility that should not be overlooked is that fracture zones exist in the confining bed. Therefore, in the second case, we assume that the flow through the confining layer is mainly through fractures. This is a clear possibility because fissured clay in the upper shallow sediments in the Love Canal area were described by Owens (1979). For flow in fissures, an effective porosity of 0.0001 would be appropriate. Using this value and the 10-foot thickness, the travel time for a tracer through the confining bed would be about 9 years. Note that adsorption would increase this value.

Of these two extreme cases, the one leading to a longer travel time is more likely. This is because the sediments comprising the confining bed are generally observed to be very moist. The moisture is expected to cause the clay to swell, hence causing the fractures to heal or close. This is supported by Owens (1979), who observed that in the Love

Canal area, the fissured clays grade to soft moist clays at about 9 to 11 feet depth. In addition, Freeze and Cherry (1979) point out that fracture zones in till and glacial lacustrine clay tend to be less permeable with depth and that highly fractured zones usually occur within several meters of the ground surface.

The implication of an expected long travel time through the confining bed is significant. If contamination is found in the Lockport Dolomite, based on the above discussion, three possible explanations, in order of plausibility, are:

(1) the confining bed was breached during original construction or during modification for disposal,

(2) contamination was caused by leakage from an upper zone due to a poorly sealed well, or

(3) the confining bed is significantly fractured.

6.6 SUMMARY

The following conclusions are based on the Lockport Dolomite model:

(1) Steady-state flow in the dolomite on a regional scale is maintained by recharge through confining beds from the topographic high near the escarpment. Discharge generally occurs along the Niagara Escarpment, toward the covered conduits, and along parts of the upper Niagara River. Locally, in the Love Canal area, the gradient is south and southwesterly toward the upper Niagara River.

(2) In the Love Canal area the vertical gradient through the confining bed is very low, with rates on the order

of 10^{-3} in/yr. The direction of flow depends on the local gradient between the shallow system and the dolomite. It could be in either direction, and as the heads fluctuate seasonally, the gradient may reverse.

(3) The Love Canal site is far enough from the covered conduits of the pump-storage project that this boundary has little effect on heads at Love Canal.

(4) Hydraulic heads in the Love Canal area were relatively insensitive to changes in transmissivity of the order 50% and less.

(5) Hydraulic heads in the Love Canal area were also relatively insensitive to changes of 50% or less in the confining bed hydraulic conductivity.

(6) Steady-state heads in the Love Canal area were most sensitive to changes in the value used to represent constant head at the upper Niagara River.

(7) If solute were to enter the Lockport Dolomite at the south end of Love Canal, and if there were no adsorption, the mean travel time to the upper Niagara River for the solute would be 1000 days. This is dependent on assumptions concerning the flow properties.

(8) Assuming a downward gradient through the confining bed, and that the confining bed was not breached and does not contain fracture zones, it would take a nonadsorbing solute on the order of hundreds to thousands of years to reach the dolomite. If adsorption occurs, travel times will be even longer.

(9) If solute is found in the dolomite and is related to waste from the Love Canal, given the long travel times calculated for the confining bed, the most likely explanation would be that the confining layer had been breached by excavation.

(10) If the confining bed were breached by excavation, downward flow could produce a ground-water high in the dolomite. Since the hydraulic heads in the two systems are nearly equal, however, it is not possible, based on hydrologic evidence alone, to determine whether the confining bed was breached.

(11) The gradient in the dolomite toward the river can be reversed by placing intercept wells near the south end of Love Canal. This can be accomplished with a total pumpage as low as 6 gal/min or 8640 gal/day.

SECTION 7.0 SHALLOW SYSTEM MODEL

7.1 NUMERICAL MODEL

7.1.1 General Information

Whereas the Lockport Dolomite was modeled as a confined aquifer, the shallow system is treated as a water-table aquifer. In water-table aquifers, transmissivity is a function of head. Making similar assumptions to those made in the last section concerning areal flow, and assuming that the coordinate axes are co-linear with the principal components of the hydraulic conductivity tensor, the flow equation may be expressed as

$$\frac{\partial}{\partial x}\left(K_{xx} b \frac{\partial h}{\partial x}\right) + \frac{\partial}{\partial y}\left(K_{yy} b \frac{\partial h}{\partial y}\right) = S_y \frac{\partial h}{\partial t} + W(x,y,t). \quad (7.1)$$

In equation (7.1),

K_{xx}, K_{yy} are the principal components of the hydraulic conductivity tensor (Lt^{-1})

S_y is the specific yield of the aquifer (dimensionless),

b is the aquifer saturated thickness (L).

Equation (7.1) is also solved in Trescott, et al. (1976) using finite-difference approximations. The resulting finite-difference equation is similar to equation (6.2). The main differences are (1) specific yield is used in the storage term and (2) the spatial-derivative coefficients are functions of hydraulic head. This results in a nonlinear problem that usually requires iteration. The system of simultaneous equations is again solved directly using D4 or alternating diagonal ordering. This procedure and the nonlinear iteration scheme are discussed in Larson (1978).

Simulations were conducted to help determine the possible hydrologic regime in the shallow system. A simplified shallow system model was constructed as shown in Plate 6 using a 24 by 12 grid. The Cayuga Creek was treated as a constant head boundary on the west. Swale No. 5, as identified by Clement (August 20, 1980), was assumed to form a no-flow boundary on the north since it approximately parallels the ground-water flow lines. The southern boundary is approximated as no-flow and was placed far enough from the swale so as not to affect the results of computed heads close to the swale. For the eastern boundary, the canal was assumed to be a no-flow boundary due to the apparent ground-water mounding in its north end, creating a ground-water divide at the location. Figure 7.1 shows the approximate grid area in relation to Swale No. 5, Love Canal, and Cayuga Creek.

The shallow system is very complex, being unsaturated in some locations and containing fill areas and swales that have permeabilities, which differ from the surrounding material. The model used to simulate flow in the shallow system is a highly idealized representation of this system. However, through its use, insight into how the flow regime

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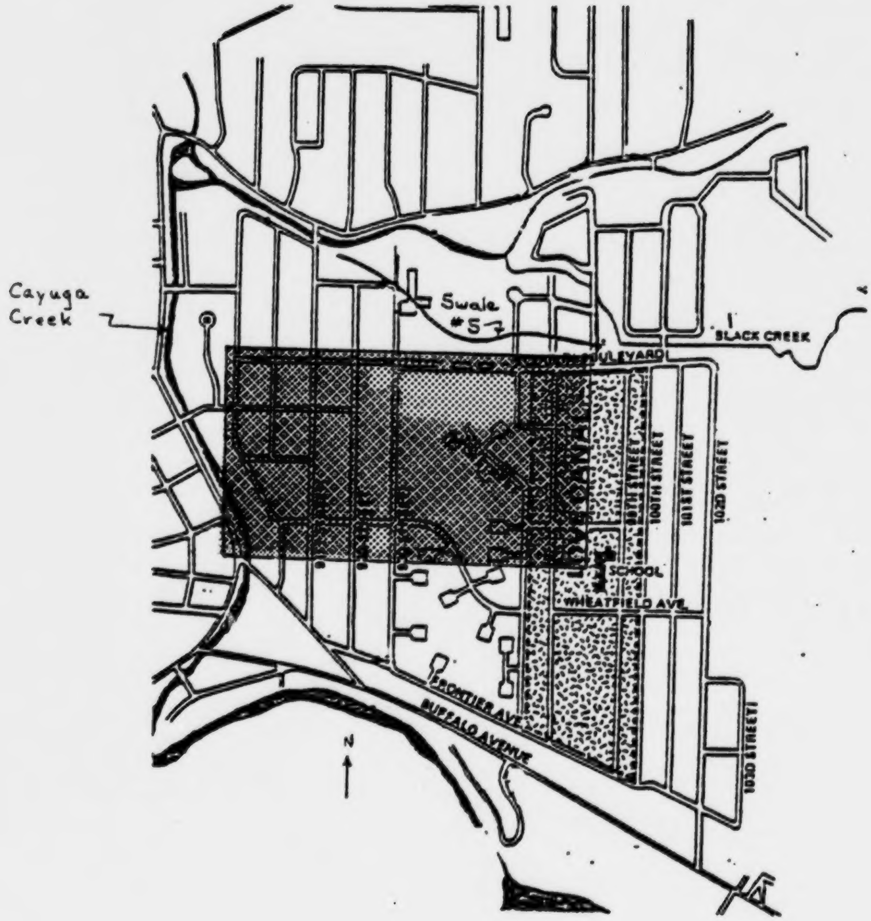

Figure 7.1 Area covered by the simplified shallow system model (stippled) of the shallow system, Love Canal, NY, showing the spatial relations among Swale #5, the Canal, and Cayuga Creek.

behaves can be gained. In an attempt to account for the major features of the shallow system, the model was used under three general hydrologic conditions: (1) homogeneous flow parameters, (2) heterogeneous parameters where a zone containing a higher hydraulic conductivity is used to represent a swale or sand lens, and (3) heterogeneous parameters where the remedial drainage system is represented by a zone of high hydraulic conductivity. These and other simulations are discussed in this section.

7.1.2 Site-Specific Assumptions

Important assumptions used in the shallow system model determined, in part, from the literature review section include:

(1) The shallow system is unconfined, porous, isotropic and heterogeneous.

(2) Ground-water flow and parameters in the shallow system can be vertically averaged.

(3) Both quasi-steady-state (annually averaged conditions) and unsteady-state flow are meaningful.

(4) The shallow system is about 12 feet thick, i.e., bottom elevation at 562 feet above mean sea level (MSL).

(5) The shallow system is composed of silty sand and clayey silt fill. The soil association of this area is described as silty loam to silty clay loam (ML to CL in Unified Soil Classification System). Table 7.1 shows that typical values of hydraulic conductivity (K) for ML to CL soil classes range from 10^{-3} to 10^{-8} cm/s (3×10^{-5} to 3×10^{-10} ft/s) and silty sands range from 10^{-3} to 10^{-6} cm/s (Brunner and Keller, 1972). Hart and Associates (1978) estimated K to be equal to or

Table 7.1 Unified soil classification system and characteristics pertinent to sanitary landfills (from Brunner and Keller, 1972).

Major Divisions		SYMBOL			NAME	Potential Frost Action	Drainage Characteristics*	Value for Embankments	Permeability cm per sec	Compaction Characteristics †	Std AASHO Max Unit Dry Weight lb per cu ft ‡	Requirements for Seepage Control
		Letter	Hatching	Color								
COARSE-GRAINED SOILS	GRAVEL AND GRAVELLY SOILS	GW	∴	RED	Well-graded gravels or gravel-sand mixtures, little or no fines	None to very slight	Excellent	Very stable, pervious shells of dikes and dams	$k > 10^{-2}$	Good, tractor, rubber-tired steel-wheeled roller	125-135	Positive cutoff
		GP	∴		Poorly graded gravels or gravel-sand mixtures, little or no fines	None to very slight	Excellent	Reasonably stable, pervious shells of dikes and dams	$k > 10^{-2}$	Good,-tractor, rubber-tired steel-wheeled roller	115-125	Positive cutoff
		GM	▦	YELLOW	Silty gravels, gravel-sand-silt mixtures	Slight to medium	Fair to poor Poor to practically impervious	Reasonably stable, not particularly suited to shells, but may be used for impervious cores or blankets	$k = 10^{-3}$ to 10^{-6}	Good, with close control, rubber-tired, sheepsfoot roller	120 -135	Toe trench to none
		GC	▨		Clayey gravels, gravel-sand-clay mixtures	Slight to medium	Poor to practically impervious	Fairly stable, may be used for impervious core	$k = 10^{-6}$ to 10^{-8}	Fair, rubber-tired, sheepsfoot roller	115-130	None
	SAND AND SANDY SOILS	SW	○	RED	Well-graded sands or gravelly sands little or no fines	None to very slight	Excellent	Very stable, pervious sections slope protection required	$k > 10^{-3}$	Good, tractor	110-130	Upstream blanket and toe drainage or wells
		SP	●		Poorly graded sands or gravelly sands, little or no fines	None to very slight	Excellent	Reasonably stable, may be used in dike section with flat slopes	$k > 10^{-3}$	Good, tractor	100-120	Upstream blanket and toe drainage or wells
		SM	▥	YELLOW	Silty sands, sand-silt mixtures	Slight to high	Fair to poor Poor to practically impervious	Fairly stable, not particularly suited to shells.but may be used for impervious cores or dikes	$k = 10^{-3}$ to 10^{-6}	Good, with close control, rubber-tired, sheepsfoot roller	110-125	Upstream blanket and toe drainage or wells
		SC	▨		Clayey sands, sand-clay mixtures	Slight to high	Poor to practically impervious	Fairly stable, use for impervious core for flood control structures	$k = 10^{-6}$ to 10^{-8}	Fair, sheepsfoot roller, rubber-tired	105-125	None
FINE-GRAINED SOILS	SILTS AND CLAYS LL IS LESS THAN 50	ML	▥	GREEN	Inorganic silts and very fine sands rock flour, silty or clayey fine sands or clayey silts with slight plasticity	Medium to very high	Fair to pour	Poor stability, may be used for embankments with proper control	$k = 10^{-3}$ to 10^{-6}	Good to poor, close control essential, rubber-tired roller, sheepsfoot roller	95-120	Toe trench to none
		CL	▨		Inorganic clays of low to medium plasticity, gravelly clays, sandy clays, silty clays, lean clays	Medium to high	Practically impervious	Stable, impervious cores and blankets	$k = 10^{-6}$ to 10^{-8}	Fair to good, sheepsfoot roller, rubber-tired	95-120	None
		OL	▦		Organic silts and organic silt-clays of low plasticity	Medium to high	Poor	Not suitable for embankments	$k = 10^{-4}$ to 10^{-6}	Fair to poor, sheepsfoot roller	80-100	None
	SILTS AND CLAYS LL IS GREATER THAN 50	MH	▥	BLUE	Inorganic silts, micaceous or diatomaceous fine sandy or silty soils, elastic silts	Medium to very high	Fair to poor	Poor stability, core of hydraulic dam, not desirable in rolled fill construction	$k = 10^{-4}$ to 10^{-6}	Poor to very poor, sheepsfoot roller	70-95	None
		CH	▨		Inorganic clays of high plasticity, fat clays	Medium	Practically impervious	Fair stability with flat slopes, thin cores, blankets and dike sections	$k = 10^{-6}$ to 10^{-8}	Fair to poor, sheepsfoot roller	75-105	None
		OH	▨		Organic clays of medium to high plasticity, organic silts	Medium	Practically impervious	Not suitable for embankments	$k = 10^{-6}$ to 10^{-8}	Poor to very poor, sheepsfoot roller	65-100	None
HIGHLY ORGANIC SOILS		Pt	≈	Orange	Peat and other highly organic soils	NOT RECOMMENDED FOR SANITARY LANDFILL CONSTRUCTION						

*Values are for guidance only, design should be based on test results

†The equipment listed will usually produce the desired densities after a reasonable number of passes when moisture conditions and thickness of lift are properly controlled

‡Compacted soil at optimum moisture content for Standard AASHO (Standard Proctor) compactive effort

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greater than 10^{-5} cm/s (3×10^{-7} ft/s). The probable range of K for the shallow system is 10^{-3} to 10^{-5} cm/s (3×10^{-5} to 3×10^{-7} ft/s).

(6) Specific yield for silty sand and clayey silt fill ranges from 3 - 30% (see Figure 7.2) with silt averaging 18% with a range of 3 - 19% (Johnson, 1967). With silt dominating and clay modifying the particle sizes, a specific yield value of 15% with a range of 10 - 20% is assumed. The specific yield can be assumed equivalent to the effective porosity in the unconfined case.

(7) The shallow system has a constant head boundary of 563 feet above MSL on the west. The location of this boundary corresponds approximately with the Cayuga Creek.

(8) The middle of the canal (parallel to its length) is approximated as a no-flow (symmetry) condition (see Plate 3).

(9) Major evapotranspiration (ET) occurs for 180 days, May through October (i.e., the growing season), at an average annual rate of 13 in/yr, varying from 11 to 15.3 in/yr. Maximum depth to which ET occurs is 6 - 10 feet with 8 foot average (see section 7.1.3 for full discussion).

(10) Recharge occurs at an annual rate of 2.7 to 7.2 in/yr with an average of 4.9 in/yr. Recharge occurs in two approximately equal surges in November-December and March-April (see section 7.1.3 for full discussion).

These assumptions are presented in Table 7.2, and those regarding evapotranspiration and recharge are discussed below.

7.1.3 Evapotranspiration and Recharge Assumptions for Shallow System

To arrive at the shallow system model, the calculations of mass balance and inflow-outflow requires estimation of the evapotranspiration (ET) and recharge(R):

$$(\text{Inflow} - \text{Outflow}) + R - ET \pm \Delta S = 0 \qquad (7.2)$$

where ΔS is the change in storage.

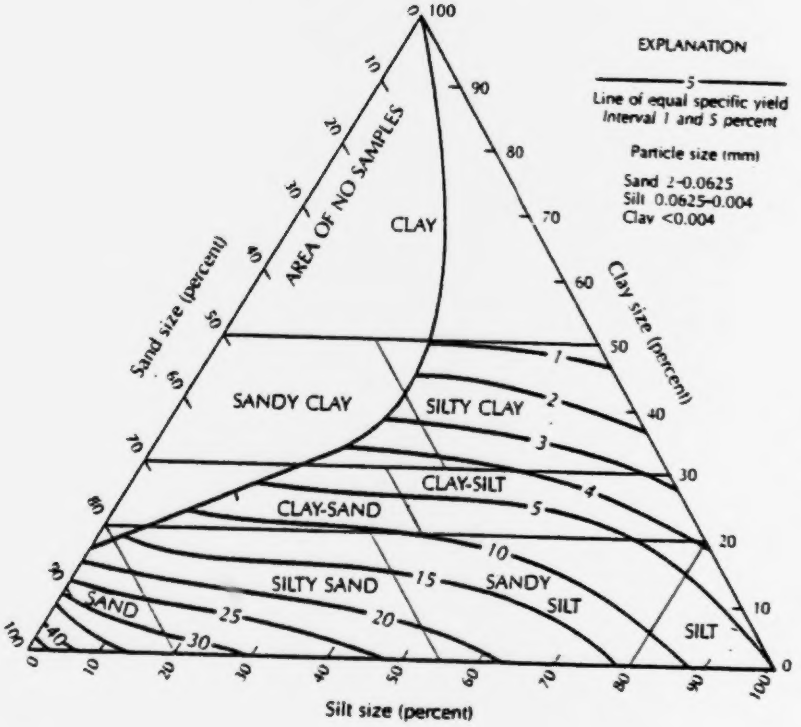

Figure 7.2 Textural classification triangle for unconsolidated materials showing the relation between particle size and specific yield. SOURCE: A.I. Johnson, U.S. Geological Survey Water Supply Paper 1662-D, 1967 (from Fetter, 1980).

Table 7.2 Summary of major assumptions for the shallow system model, Love Canal, NY.

Model Assumption	Actual Conditions	Comment
Unconfined with no capillary fringe	Unconfined with significant capillary fringe	Unsaturated zone is neglected because data lacking
Porous	Porous	None
Isotropic	Probably isotropic in horizontal plane	None
Heterogeneous	Heterogeneous	Two zone approach attempts to account for effects of heterogeneity
Aquifer properties can be vertically averaged	Properties vary with depth	Assumption consistent with available data
Base of shallow system at 562 ft above MSL, thickness therefore ranges from 8 to 14 feet	Aquifer base and thickness variable due to lenticular form of deposits	Assumption consistent with available data
No-flow eastern boundary	Ground-water mounding in north end of canal	Mound forms a divide to ground-water flow creating no-flow (symmetry) condition in middle of mound

Table 7.2 (continued)

Model Assumption	Actual Conditions	Comment
No-flow northern boundary along Swale #5	Flow line parallels boundary and Swale #5	No flow across boundary parallel to flow line.
Constant head western boundary	Cayuga Creek with relatively constant water level	None
No-flow southern boundary	Uncertain	The simplified, model does not go far enough south to meet Niagara River. Boundary is placed far away from Swale #5 to have no effect.
ET averages 13 in/y with range of 11-15.3 in/y	Uncertain	ET varies annually and occurs mostly in May-October.
Recharge averages 4.9 in/y with range of 2.7-7.2 in/y	Uncertain	Recharge varies annually with precipitation and varies over region with soil and vegetation conditions.
Constant hydraulic conductivity (K) ranges 10^{-3}-10^{-5} cm/s	$>10^{-5}$ cm/s (Hart and Assoc.,1978)	See comment for heterogeneous
Constant specific yield (or effective porosity) averages 15% with range of 10-20%	Uncertain	Specific yield varies throughout aquifer but assume constant specific yield over larger scale.

To accurately determine evapotranspiration, estimates of ET were obtained by two methods. The first approach is to consult a general reference. Miller (1977) provides estimates calculated over broad regions of the U.S. and gives 450 mm (17.7 inches) for annual ET for the region between the Great Lakes and the St. Lawrence River.

Another method to estimate ET on a local scale is by using pan evaporation data. Correlating ET to pan evaporation requires that a correction factor be applied to account for the physical differences between the pan and the ground. Bouwer (1978) summarizes the use of pan evaporation for estimating ET. To select the appropriate correction factor, wind speed, upwind fetch and relative humidity are required. For the Love Canal area, these parameters are estimated as (NOAA, 1978-1979):

Wind (km/day) = 75 km/day
Upwind fetch (m) = 10 m
Relative Humidity (%) = 40-70%

The pan correction factor for the above values is 0.80 for wet green grass and 0.65 for dry-surface ground. Since the surface conditions approach the dry-surface ground more often than the wet surface, the correction factor should be weighted towards the lower value; thus, a value of 0.7 is taken as the pan correction factor.

Additionally, vegetation has differing moisture demands during the course of the growing season with lower demands in the early spring when leaf area is still small and in the fall when growth has slowed. The ratios of actual ET at partial cover to that at full cover is the crop coefficient. Bouwer (1978) cites values for various vegetation, for instance:

citrus orchards = 0.5-0.6

pasture = 0.87 (constant throughout growing season)

corn = 0.20 early, increasing to 0.99 in middle and decreasing to 0.17 at the end of the growing season.

A crop coefficient for trees may be assumed to be about 0.5 in the spring, 1.0 in the summer, and declining to 0.1 in the fall, giving a weighted average of 0.7. Grass' crop coefficient can be assumed to be slightly less than pasture since grass is kept mowed, e.g., less leaf area, and grass' value is taken to be 0.8.

A weighted crop coefficient for the study area of mixed trees and grass is obtained with an estimated 20% tree and 80% grass coverage. This provides an overall crop coefficient of 0.78.

The National Oceanic and Atmospheric Administration maintains a class A evaporation pan in Lockport, NY close to Love Canal. Data obtained for 1978 and 1979 show 29.43 and 27.57 inches, respectively. Assuming an annual pan evaporation rate of 28 inches, the ET would be calculated as:

$$\begin{aligned} ET &= (\text{Pan Evaporation})(\text{Correction Factor})(\text{Crop Coefficient}) \\ &= (28 \text{ inches})(0.70)(0.78) \\ &= 15.3 \text{ inches, or} \\ &\quad 4.0 \times 10^{-8} \text{ ft/s averaged over the year.} \end{aligned}$$

Note the comparison between the two methods of determining ET, that is, 17.7 inches for the region versus 15.3 inches for the local area. Dr. C.H.V. Ebert of the Department of Geography, SUNY, Buffalo (oral communication, 11/10/80) believes the ET in the Love Canal area to be significantly less than that measured at Lockport due to microclimate differences in temperature and humidity. This may reduce ET by possibly an additional 15%, or to about 13 in/yr.

Due to the surface area of pavement, an additional reduction in ET may be assumed. Over the shallow system model area, approximately 15% of the land surface is paved, resulting in inhibition of ET. Since the degree of pavement is relatively consistent over the area, an additional constant reduction factor of 0.15 for ET has been applied, reducing ET to about 11 in/yr. See Table 7.1 for final values used.

The computation of ET in the model requires a maximum depth to which ET occurs. When the water table falls below this maximum depth, ET ceases. ET increases linearly in the model as the water table rises to a maximum ET rate when the water table is at ground surface. The maximum depth at which ET occurs is controlled mainly by maximum rooting depth. In the Love Canal area, maximum rooting depth is 6-10 feet due to the relatively tight clays occuring at those depths and the shallow water tables (oral communication with Dr. C.H.V. Ebert, SUNY at Buffalo, 11/10/80).

One method to estimate recharge is by equation (7.3).

$$\text{Recharge} = \text{Precipitation} - \text{Runoff} - \text{ET} \qquad (7.3)$$

Precipitation averages 32.6 in/yr as reported in Table 7.3, and McGuiness (1963, Plate 1) indicates runoff in the Niagara Falls area to be 15-20 in/yr. Since this area is well vegetated and relatively flat, runoff would be decreased, probably to 15 inches or less. Taking the ET range of 11-15.3 in/yr calculated in the previous section, substitution into equation (7.3) provides a value of recharge 2.3 to 6.6 in/yr.

A more site-specific estimation of recharge is by analysis of well hydrographs such as shown in Figure 7.3. Clement and Associates (1980) provided the water level data for standpipes installed at Love Canal, although for only the time interval of November 1978 through June 1979. Figure 7.3 clearly illustrates seasonal fluctuations of the water levels. Total changes in head range from 1.5 to 4 ft. Assuming a porosity of 15% enables conversion of the well head changes into inches of recharge, resulting in a recharge rate of 2.7 to 7.2 in/yr, with an average of 4.9 in/yr.

Table 7.3 Temperature and Precipitation at Lockport, NY (USDA, 1972).

[Based on a 30-year period of record]

Month	Temperature				Precipitation				
	Average daily maximum	Average daily minimum	7 years in 10 will have--		Average total	3 years in 10 will have--		Snow	
			Maximum temperature equal to or higher than--	Minimum temperature equal to or lower than--		More than--	Less than--	Average total	7 years in 10 will have more than--
	° F.	° F.	° F.	° F.	In.	In.	In.	In.	In.
January------	32	17	46	1	2.5	2.7	1.7	15	10
February-----	34	18	47	3	2.5	2.8	2.0	13	9
March--------	41	24	57	14	2.4	3.0	1.9	10	4
April--------	55	35	72	24	3.0	3.5	2.4	2	(1/)
May----------	67	45	80	32	3.1	3.7	2.2	(1/)	(2/)
June---------	77	55	88	44	2.4	3.1	1.5	--	--
July---------	82	60	90	50	2.9	3.4	2.2	--	--
August-------	80	59	88	48	3.2	4.4	2.4	--	--
September----	73	51	85	37	2.7	3.5	2.2	--	--
October------	62	42	78	30	2.7	3.4	1.2	(1/)	(2/)
November-----	48	33	65	20	2.8	3.4	2.1	5	2
December-----	36	22	51	6	2.4	2.0	1.9	11	6
Year-------	57	38	91	-2	32.6	35.0	30.4	56	46

1/ Trace.

2/ One year in 10 will have more than a trace.

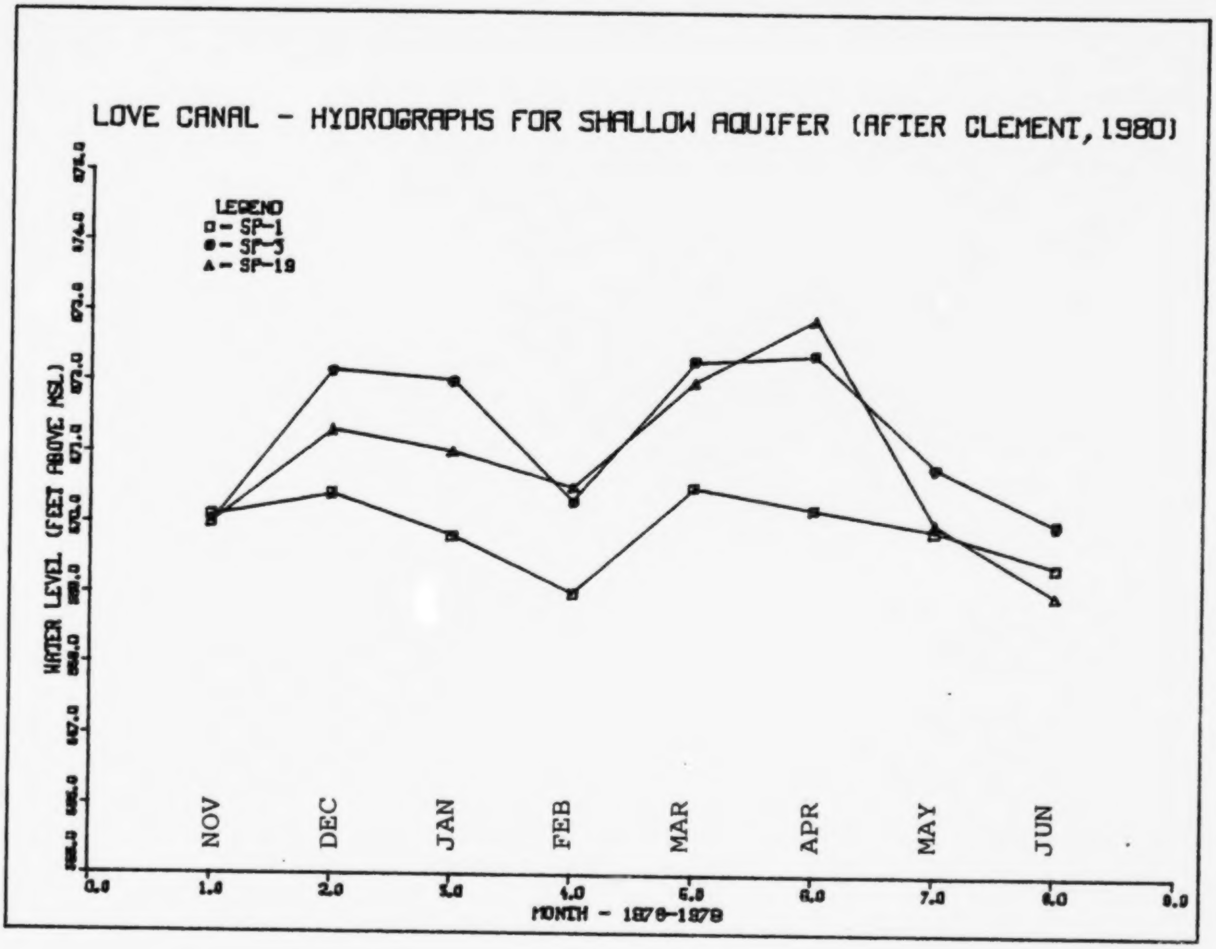

Figure 7.3 Well hydrographs for the shallow system constructed from data reported by Clement (1980) for stand pipes (SP) nos. 1, 3 and 19.

This range compares favorably with the estimates derived in equation (7.3) above. The locally estimated values for recharge of 2.7 to 7.2 in/yr are used in the shallow system model. Figure 7.4 graphically summarizes the ET and recharge values utilized in the shallow system model.

ET is the controlling factor on amount of recharge to the shallow system. Figure 7.5 provides an idealized well hydrograph incorporating the hydrographs of Figure 7.3. With fairly constant precipitation per month throughout the year (see Table 7.3), the seasons act as a switch, turning ET on in the spring and off in the fall, greatly reducing recharge from late spring to fall and allowing recharge in the late fall and early spring.

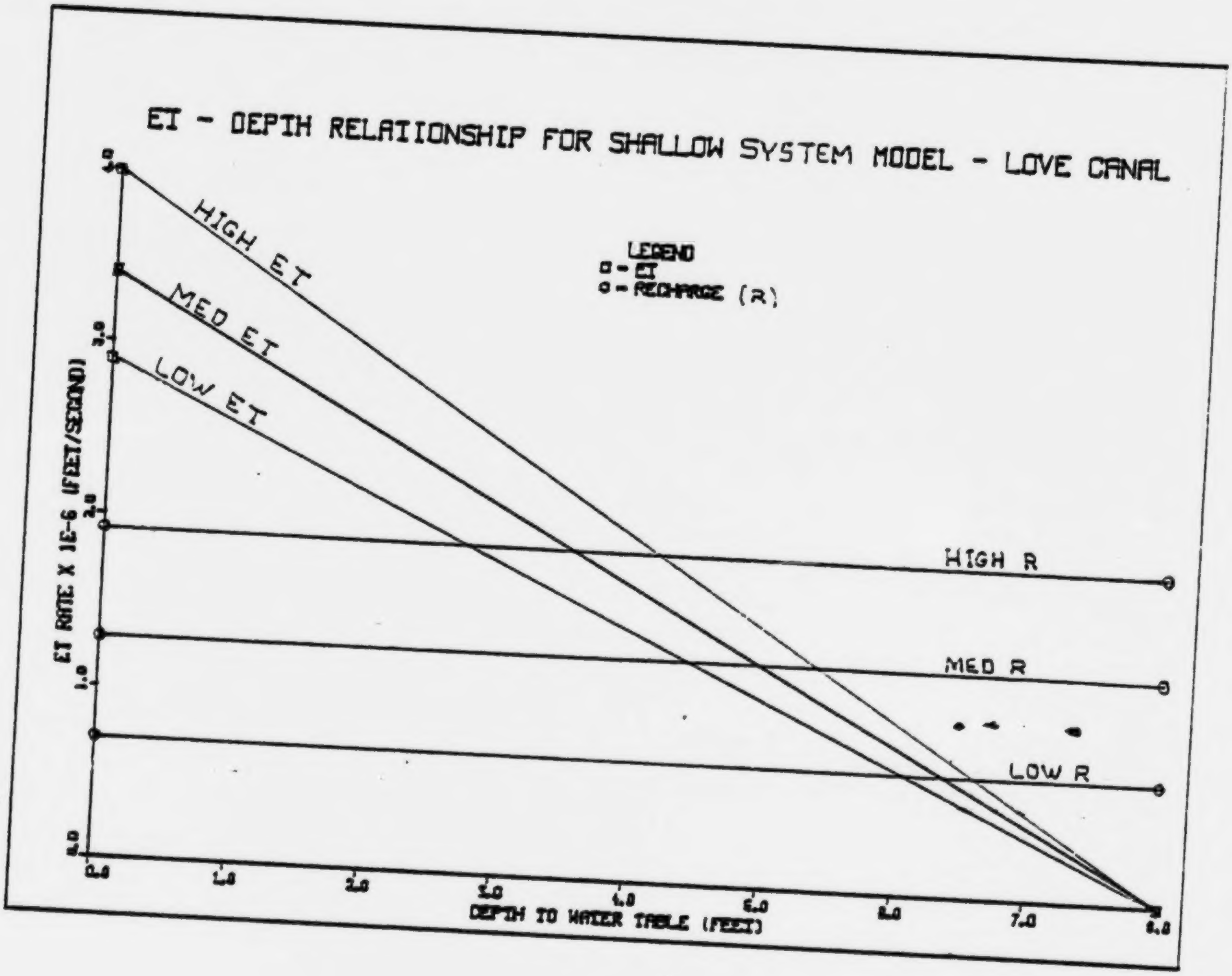

Figure 7.4 ET and recharge (R) rates versus depth for the shallow system model.

High ET is 15.3 in/yr (4.0 x 10^{-8} ft/s)
Med ET is 13.0 in/yr (3.4 x 10^{-8} ft/s)
Low ET is 11.0 in/yr (2.9 x 10^{-8} ft/s)

Maximum depth of ET is 8 feet.

High R is 7.2 in/yr (1.9 x 10^{-8} ft/s)
Med R is 4.9 in/yr (1.3 x 10^{-8} ft/s)
Low R is 2.7 in/yr (0.7 x 10^{-8} ft/s)

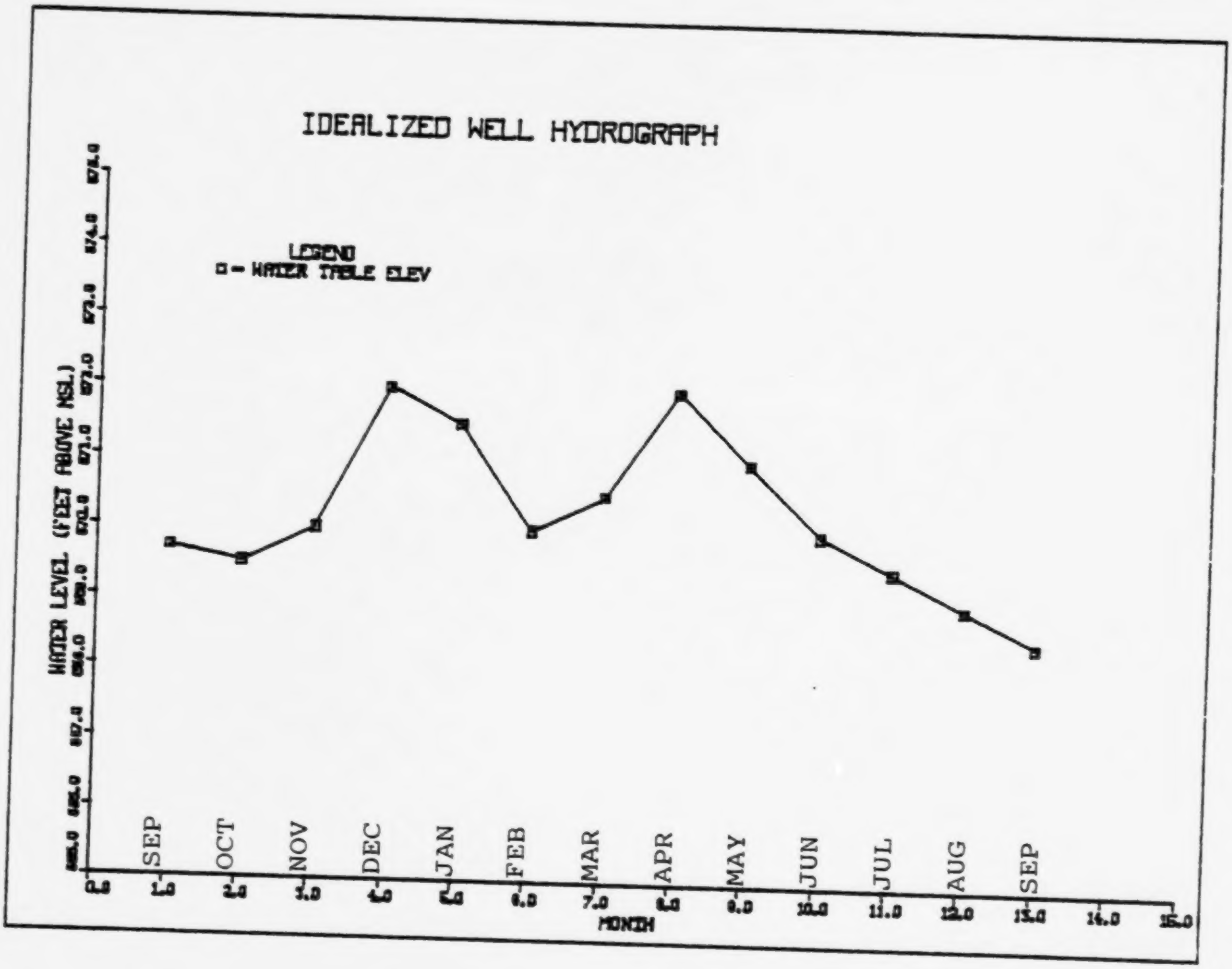

Figure 7.5 Idealized well hydrograph for shallow system, Love Canal, NY.

7.2 SENSITIVITY ANALYSIS FOR QUASI-STEADY-STATE CONDITIONS WITHOUT REMEDIAL MEASURES

Figure 7.6 shows a cross-section of initial, or starting conditions prior to remedial actions for the shallow system model with land surface, location of constant head creek, and aquifer base.

7.2.1 Hydraulic Conductivity

The hydraulic conductivity (K) of the shallow system has been estimated to be between 10^{-3} and 10^{-5} cm/s (3×10^{-5} and 3×10^{-7} ft/s). Since a more definitive shallow system K cannot be arrived at through aquifer tests, what are the effects of different K values on the interpretations of the shallow hydrologic regime? Sensitivity runs were conducted for which only K was systematically varied as follows:

Varied Parameter:

$K_1 = 3 \times 10^{-5}$ ft/s

$K_2 = 3 \times 10^{-6}$ ft/s

$K_3 = 3 \times 10^{-7}$ ft/s

Constant Parameters:

Medium ET = 13 in/yr
Medium Recharge = 4.9 in/yr
Depth of ET = 8 ft

Figure 7.7 shows the resulting variation of head in the shallow system for the three values of K. The three water tables differ very little with average gradients in

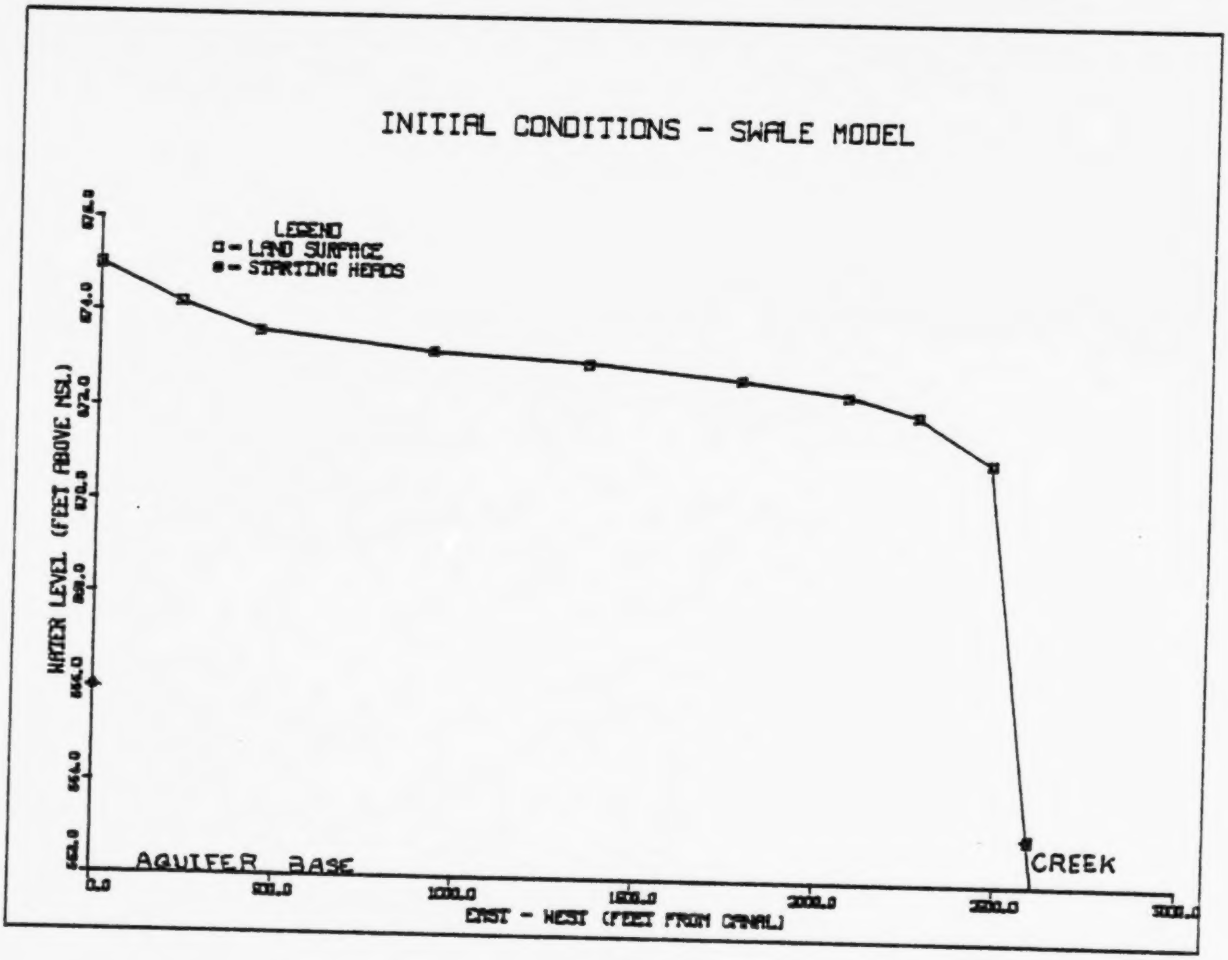

Figure 7.6 Cross-section of the shallow-system model showing initial conditions prior to remedial actions for land surface, aquifer base, and constant head creek.

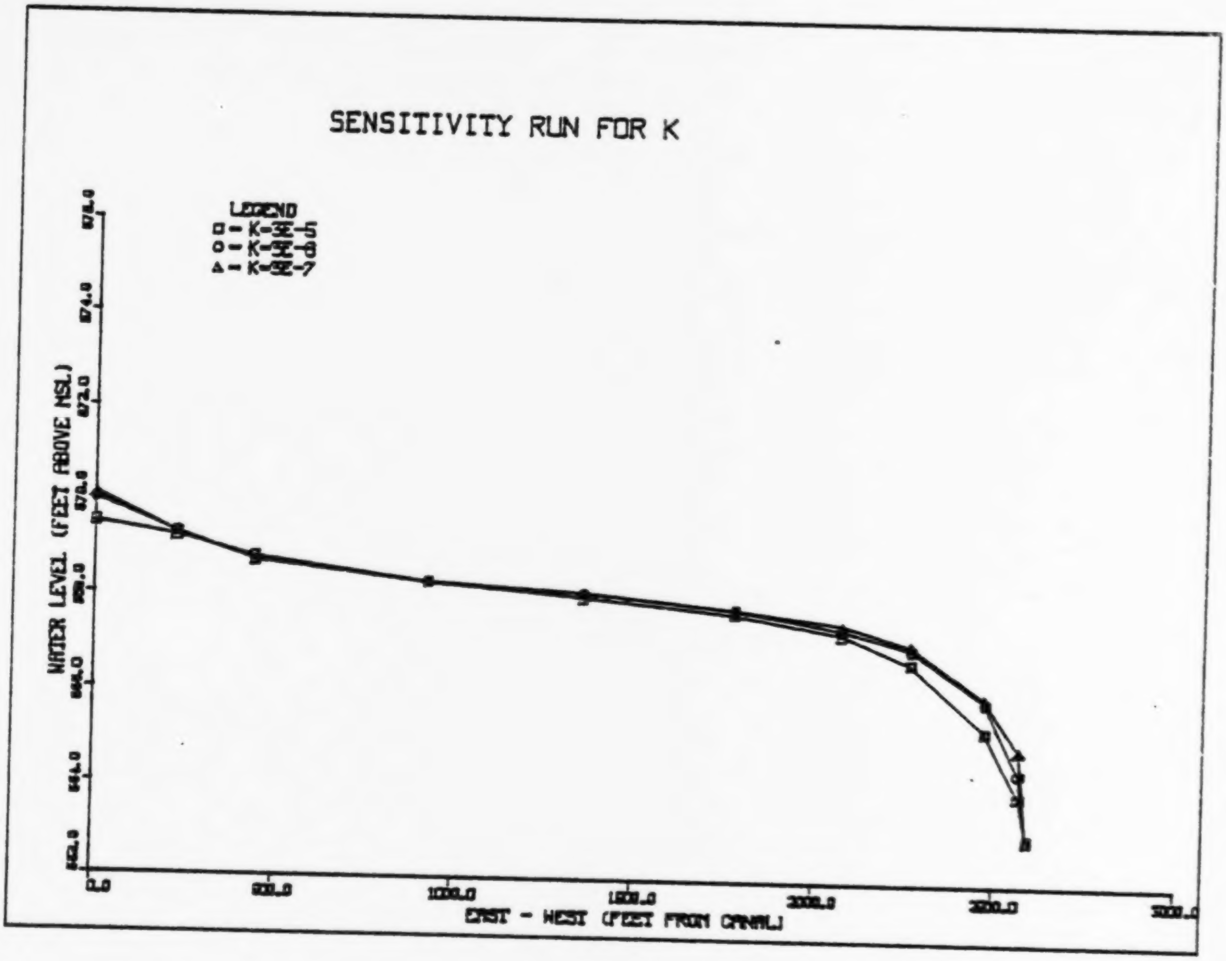

Figure 7.7 Results of sensitivity runs with varying hydraulic conductivities for the shallow system, Love Canal. Top curve represents K of 3 x 10^{-7} ft/s; middle curve, 3 x 10^{-6} ft/s; and bottom curve, 3 x 10^{-5} ft/s. Average gradient over 0 - 1776 ft from canal is 0.001 - 0.0013. ET is 13 in/yr with 8 ft depth and recharge is 4.9 in/yr.

the upper half of the curves (0-1776 ft from canal) ranging from 0.0010 for K of 3 x 10^{-5} ft/s to 0.0013 for K of 3 x 10^{-7} ft/s. For the range of hydraulic conductivities considered, the water-table position is insensitive to K. As will be seen, the position is controlled by ET-recharge relationships.

7.2.2 Evapotranspiration and Recharge Effects

Uncertainty in ET and recharge may have considerable effects on the analysis of the shallow system. Combining ET and recharge parameters in high-low, medium-medium, and low-high pairs produced the resultant shallow system heads shown in Figure 7.8. Increasing ET and decreasing recharge will cause a lower water table, while decreasing ET and increasing recharge will raise the water table. With the ranges in ET and recharge utilized here, i.e., ET ranges 11-15.3 in/yr, averages 13 in/yr.; Recharge ranges 2.7-7.2 in/yr, averages 4.9 in/yr., the water table may vary by four feet. This will affect the flow rate to the creek and to the French drain, but the gradient in the area of concern nearer the canal is not affected.

Likewise, varying the maximum depth to which ET occurs will cause changes in head. A shallower depth for eliminating ET will raise the heads, while a deeper ET depth will lower the heads. This is illustrated in Figure 7.9.

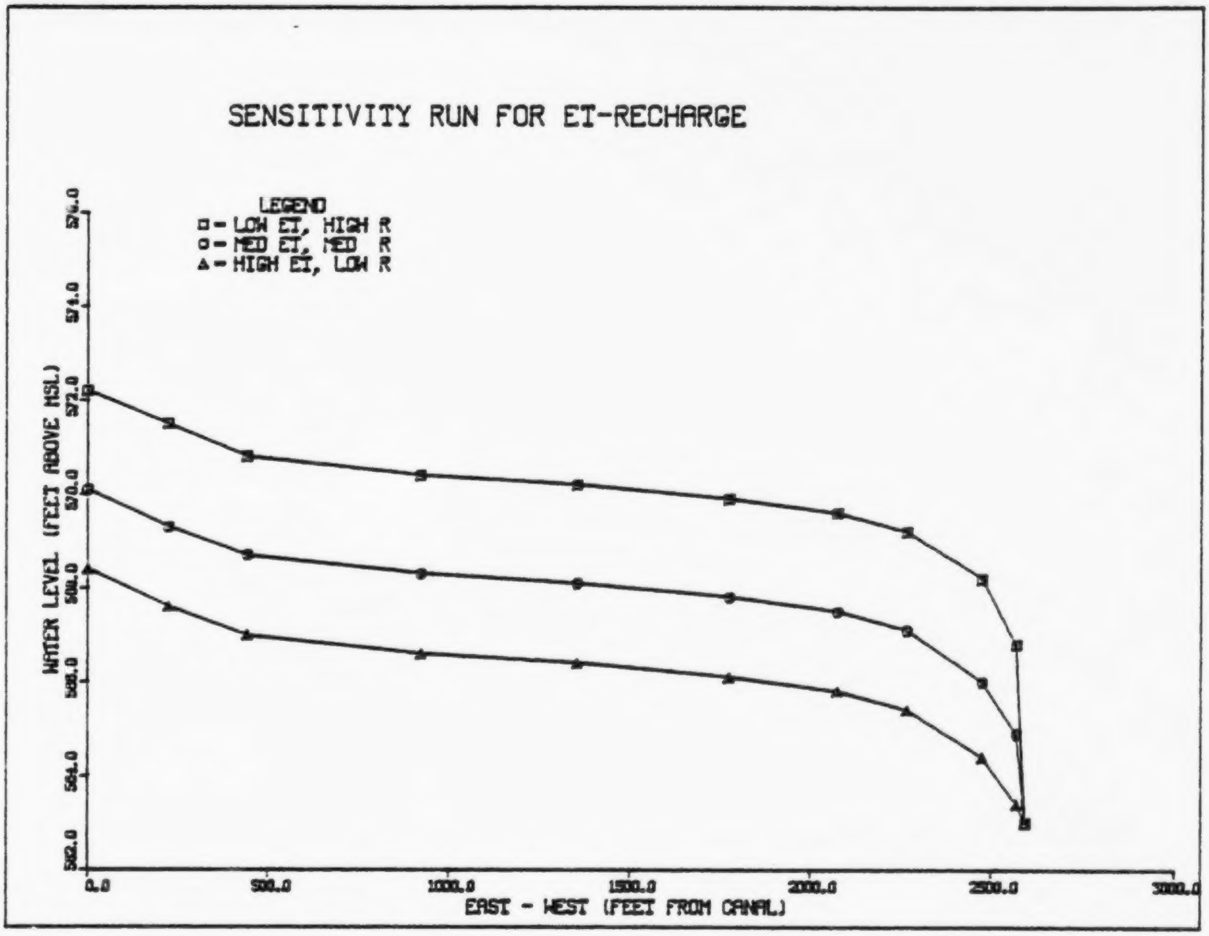

Figure 7.8 Results of sensitivity runs with varying ET and recharge rates for the shallow system, Love Canal. Increasing ET and decreasing recharge (R) causes decreased heads. Top curve represents low ET (11 in/yr) and high R (7.2 in/yr). Middle curve results from medium ET (13 in/yr) and medium R (4.9 in/yr). Bottom curve represents high ET (15.3 in/yr) and low R (2.7 in/yr). $K = 3 \times 10^{-6}$ ft/s.

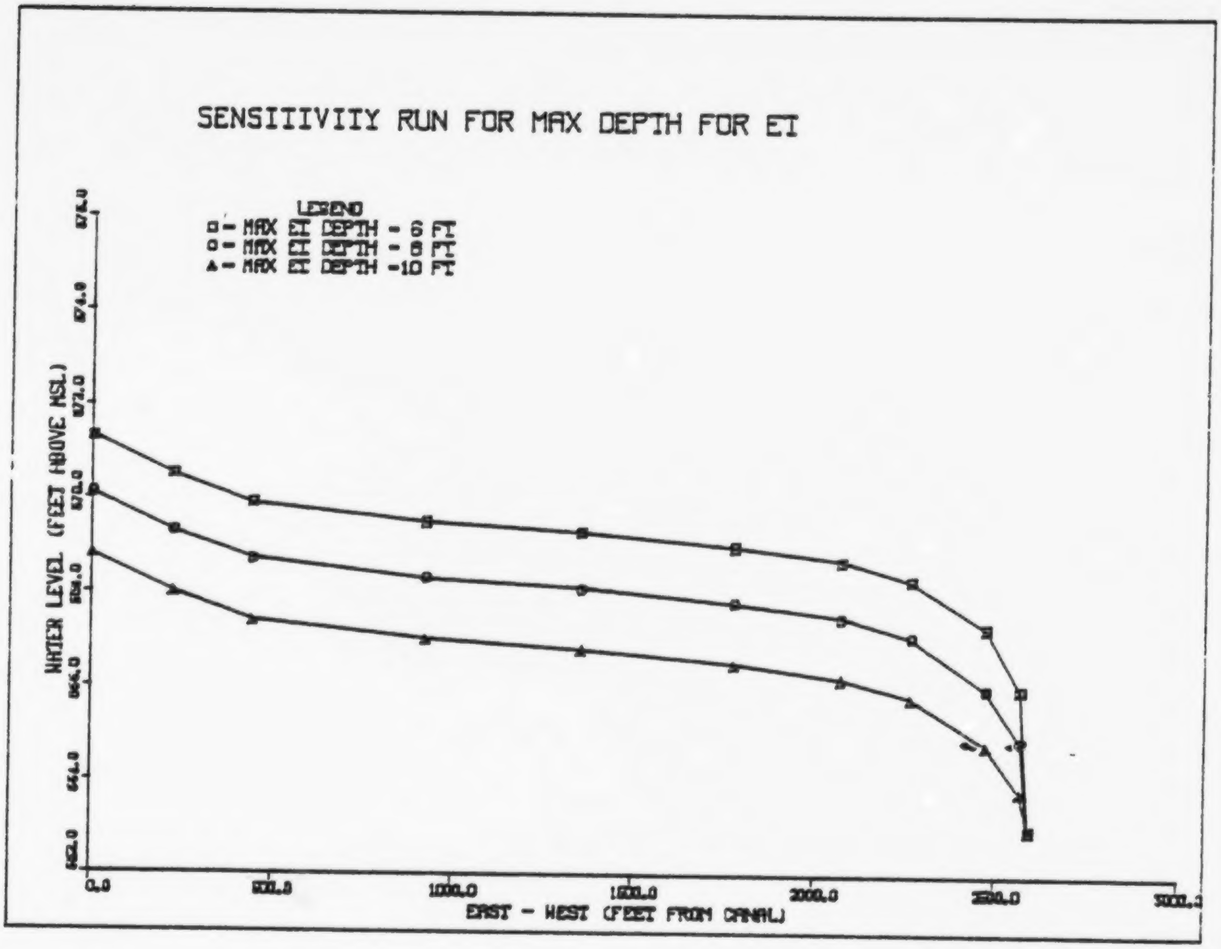

Figure 7.9 Results of sensitivity runs with varying maximum depth of ET for the shallow system, Love Canal. Top curve represents 6 ft maximum ET depth; middle curve, 8ft; and bottom curve, 10 ft. $K = 3 \times 10^{-6}$ ft/s, ET is 13 in/yr and recharge is 4.9 in/yr.

These effects will occur over the seasonal cycles operating in the region. Spring through fall brings high ET and low recharge while fall through spring brings low ET and high recharge, as outlined in section 7.1.3 and Figure 7.4.

7.2.3 Swale (or Sand Lens) Effects

Swales in the Love Canal area have been described by various sources as reported in the literature review of section 3.3. A possible effect of importance to this study, which the swales may produce, is pathways of increased hydraulic conductivity. Actual values of K for the swales are unknown. If they do have a higher K than the surrounding material, then are the swales of significant importance? Freeze and Cherry (1979) provide typical ranges of K for various earth materials and give silty sand a K value of 3×10^{-3} to 3×10^{-7} ft/s while clean sand has a K between 3×10^{-2} and 3×10^{-6} ft/s. Utilizing the simplified model of the shallow system, several sensitivity runs were conducted to provide insight into the possible magnitude of the swale effects. This section also applies to sand lenses which would have effects similar to those of a swale.

First, we examine what changes occur in shallow system hydraulics by a higher K swale. Figure 7.10 (east-west cross-section from Love Canal to Cayuga Creek) illustrates the different water tables associated with a shallow system

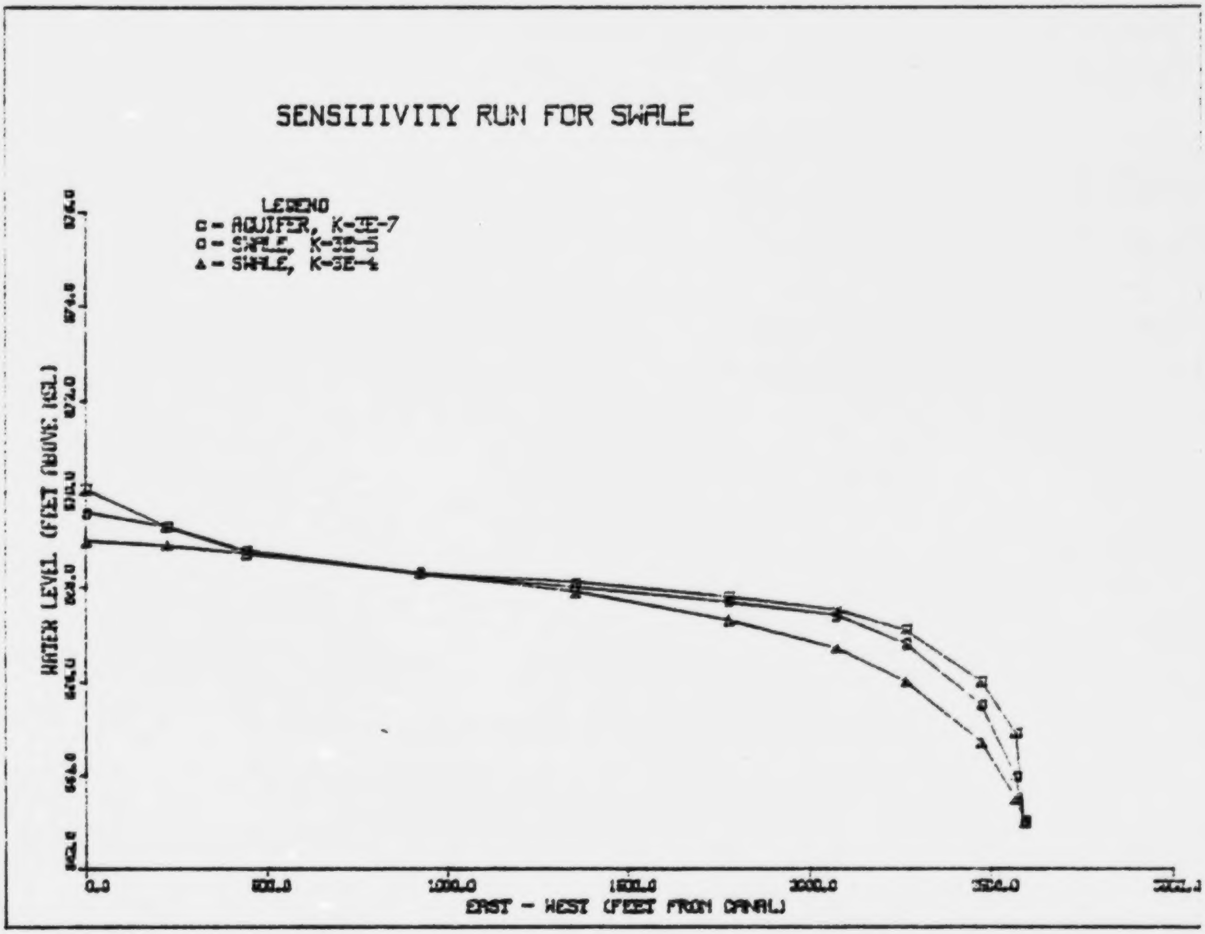

Figure 7.10 Results of sensitivity runs with swale of varying hydraulic conductivity. Top curve represents head in the shallow system with K of 3×10^{-7} ft/s. Middle and bottom curves represent heads in the center of swales with K of 3×10^{-5} or 3×10^{-4} ft/s, respectively. Specific yield is 15%, ET is 13 in/yr and recharge is 4.9 in/yr.

having a K of 3×10^{-7} ft/s and a swale of either 3×10^{-5} or 3×10^{-4} ft/s. The swale produces a significant change in gradient only for swale hydraulic conductivities that are greater than that of the surrounding material by at least two orders of magnitude. The gradient of the shallow system (with K of 3×10^{-7} ft/s) is 0.0013, while both swales with K of 3×10^{-5} and 3×10^{-4} ft/s have gradients of 0.001. While these gradients are basically the same, the hypothetical swales will have higher flow rates and higher velocities by the factor of the difference in K. Thus, while a shallow system with a K of 3×10^{-7} ft/s and a gradient of .0013 has a flux of 3.9×10^{-10} ft/s per square foot of cross-sectional area of flow, the swale with a K of 3×10^{-4} ft/s would have a flux of 3×10^{-7} ft/s per square foot. Assuming an effective porosity of 15%, the velocity associated with the material having a K of 3×10^{-7} ft/s will be 0.08 ft/yr while the velocity in the hypothetical swale with a K of 3×10^{-4} ft/s will be 63 ft/yr - three orders of magnitude higher.

Table 7.4 lists ground-water flux rates per unit cross-sectional area and velocities for various hypothetical shallow systems and swales/sand lenses. For example, a case where the shallow system had a K of 3×10^{-7} ft/s and a swale had a K of 3×10^{-4} ft/s, the ground water would move 0.08 ft/yr in the shallow system and would move 63 ft/yr in

Table 7.4 Flux rate and velocity of ground water for various hypothetical shallow systems and swales/sand lenses.*

Hydraulic Conductivity K(ft/s)	Effective Porosity ϕ	Gradient i(ft/ft)	Flux Rate per ft^2 $\frac{Q}{A}$(ft/s) = Ki	Velocity v(ft/yr) = $\frac{Ki}{\phi}$
Shallow Systems:				
A. 3×10^{-7}	0.15	0.0013	4×10^{-10}	0.08
B. 3×10^{-6}	0.15	0.0012	4×10^{-9}	0.76
Swales/Sand Lenses:				
A. 3×10^{-5}	0.15	0.001	3×10^{-8}	6.3
B. 3×10^{-4}	0.15	0.001	3×10^{-7}	63

* Derived from: $\frac{Q}{A} = Ki$ and $v = \frac{Ki}{\phi}$

where $\frac{Q}{A}$ = flux rate per unit cross-sectional area (ft^3/s/ft^2)

v = velocity (ft/s)
K = hydraulic conductivity (ft/s)
i = gradient (ft/ft)
ϕ = effective porosity (dimensionless)

the swale. Flux rates through equal cross-sectional areas of the shallow system and swale would be 4×10^{-10} and 3×10^{-7} $ft^3/s/ft^2$, respectively. About 3800 ft^3/yr of ground water would flow through a swale of 10 ft depth and 40 ft width.

7.3 REMEDIAL ACTION EFFECTS ON SHALLOW SYSTEM

As briefly reviewed in section 3.4, remedial actions at Love Canal have consisted of a clay cap to retard infiltration of precipitation into the canal and a French drain around the canal to intercept any lateral migration of fluids out of the canal. Both remedial actions affect the shallow system hydrology to varying degrees. As described below, the shallow system model has been modified to assist in the investigation of the possible effects of the remedial actions. Here unsteady flow conditions are assumed in the model.

7.3.1 French Drain Flow Rate Data and Shallow System Hydraulic Conductivity

The French drain is modeled as a row of cells four feet wide in row 22 of the model. This places the hypothetical trench about 50 ft from the canal edge. Since the trench was constructed approximately 15 ft in depth, the French drain acts as a constant head sink and was set at a constant head elevation of 562.1 ft, one-tenth foot above the base of the shallow system model. The computer code utilized for the shallow system provides a printout of constant head flux rates for each cell, i.e., the volume of groundwater discharged (or recharged) at constant head cells per time. Data on volume of treated water collected by the drain has been recorded at the Love Canal treatment plant. Dr. Nick Kolak, New York State Department of Environmental Conservation, provided data for the months of Jan., March, June and Sept., 1980, as shown in Table 7.5. These data enable the estimation of the overall hydraulic conductivity of the shallow system by varying certain parameters and holding others constant until a match is obtained between the modelled flux rate in the constant head drain cells and the measured flux rate in Table 7.5.

Figures 7.11 and 7.12 show results of sensitivity runs for shallow system K's of 3×10^{-7} and 3×10^{-6} ft/s, respectively, and specific yields of 15% for various combinations of ET and recharge. ET and recharge values used for these runs are the minimum, maximum, and average values reported in Table 7.2. The brackets on the figures indicate the data for treated volumes as reported by Dr. Kolak in Table 7.5. These reported flow rates range across time within the brackets since the French drain construction occurred over approximately a 6 month time interval. Since it is uncertain when the French drain and associated construction began discharging, the field data has a certain amount

Table 7.5 Monthly volume of water treated by the Treatment Plant at Love Canal.

Month	Total Volume[1] gal	Average Daily Volume ft^3/s	Average Flux Rate per Lineal Foot of Drain[2] ft^3/s
January 1980	474,660	2047	2.6×10^{-6}
March 1980	390,650	1685	2.2×10^{-6}
June 1980	318,740	1420	1.8×10^{-6}
September 1980	235,050	1047	1.4×10^{-6}

[1] Provided by Dr. Nick Kolak, New York State Department of Environmental Conservation.

[2] Dr. Kolak gave 8958 ft for the total length of French drain. This includes the main drains and laterals.

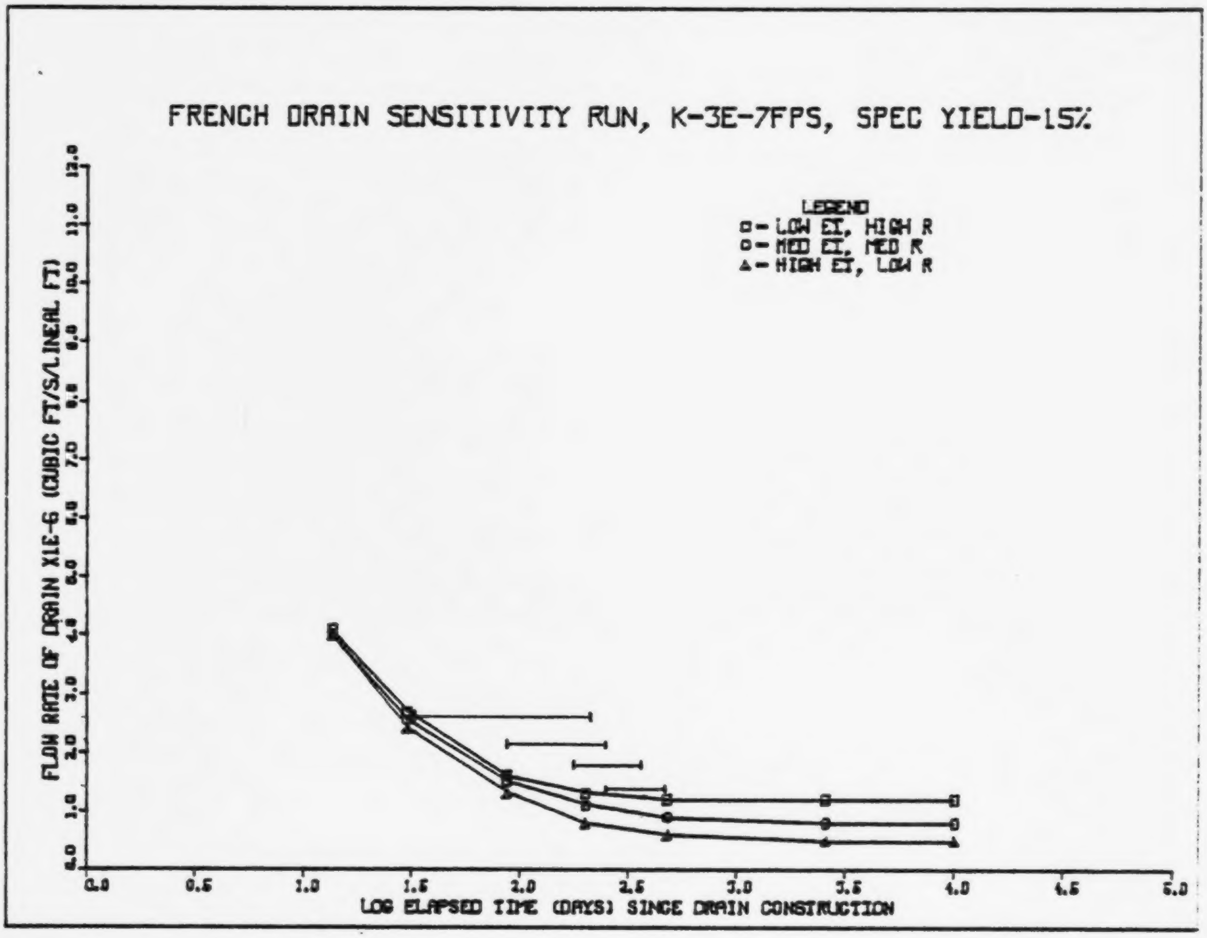

Figure 7.11 Results of sensitivity runs for estimating hydraulic conductivity of the shallow system by history matching flow rate data collected for the French drain with modeled results based on K of 3×10^{-7} ft/s and specific yield of 15%;top curve represents low ET (11 in/yr) and high recharge (7.2 in/yr); middle curve represents medium ET (13 in/yr) and medium recharge (4.9 in/yr), and bottom curve represents high ET (15.3 in/yr) and low recharge (2.7 in/yr). Brackets represent actual field data collected at Love Canal treatment plant with uncertainty in elapsed time.

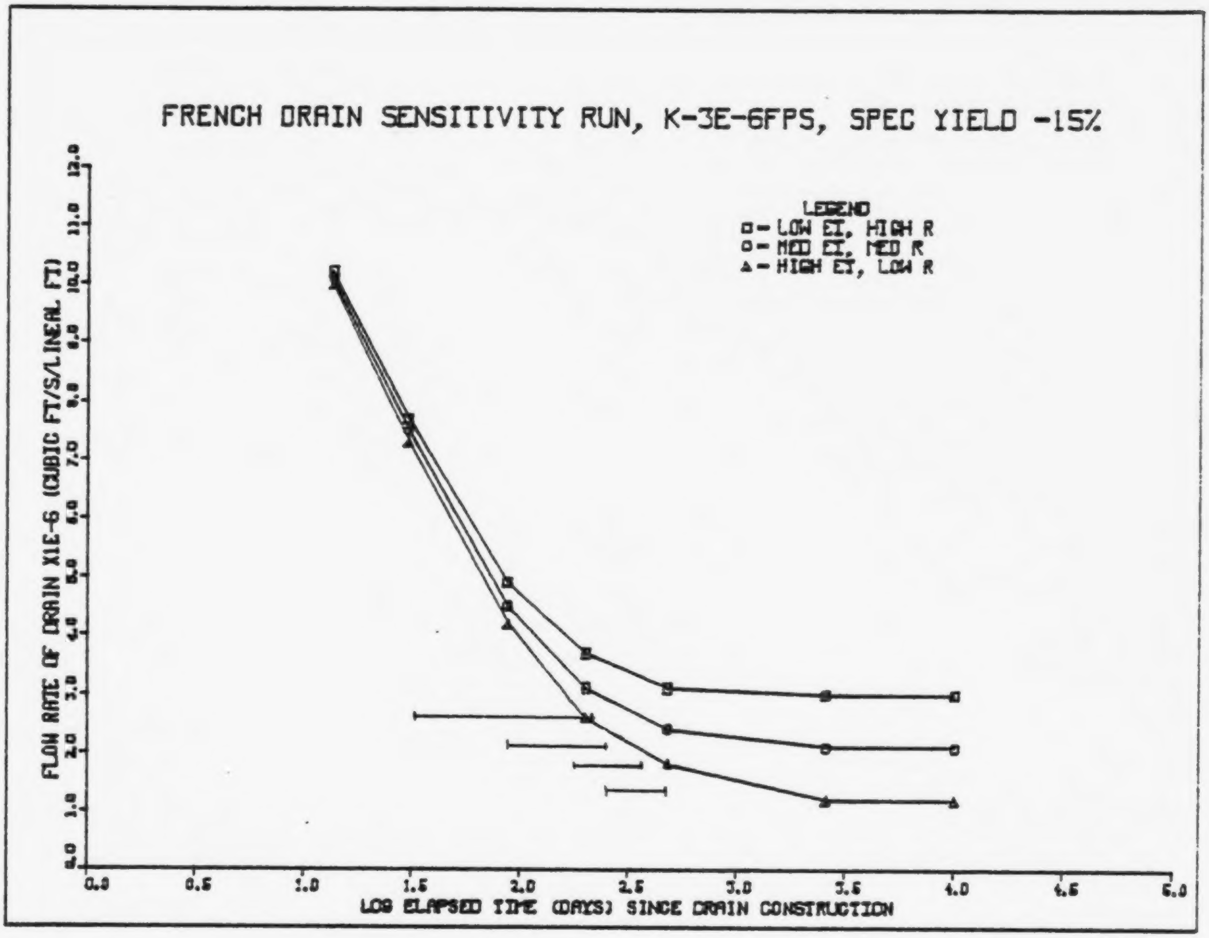

Figure 7.12 Results of sensitivity runs for estimating hydraulic conductivity of the shallow system by history matching the flow rate data collected for the French drain with modeled results based on K of 3×10^{-6} ft/s and specific yield of 15%; top curve represents low ET (11 in/yr) and high recharge (7.2 in/yr); middle curve, medium ET (13 in/yr) and medium recharge (4.9 in/yr); and bottom curve, high ET (15.3 in/yr) and low recharge (2.7 in/yr). Brackets represent actual field data collected at Love Canal treatment plant with elapsed time uncertainty.

of uncertainty in the elapsed time since the drain began operating.

Effective porosity, or specific yield, will affect the rate of drainage until steady state is achieved. Figures 7.13 and 7.14 show the effects of various specific yields on the shape of the curves, illustrating the effects of specific yield on drain flow rates prior to steady state.

Definite conclusions can be drawn from Figures 7.11 - 7.14. An averaged hydraulic conductivity for the shallow system is between 3 x 10^{-6} and 3 x 10^{-7} ft/s with a specific yield of 10-15%. The observed flow rates are completely bracketed by the modeled flow rate curves. Since the season over which the observed data were collected is characterized by high ET and low recharge, the modeled curves in Figures 7.13 and 7.14 provide the closest match of the observed data.

The average value of hydraulic conductivity of approximately 10^{-6} ft/s estimated in this analysis is significantly higher than the value obtained from analysis of the slug test in the overburden cluster wells (section 4.4). This discrepancy is not unexpected. The value estimated by analysis of the drain system represents an average hydraulic conductivity for an area on the scale of the drain system. The slug test, on the other hand,

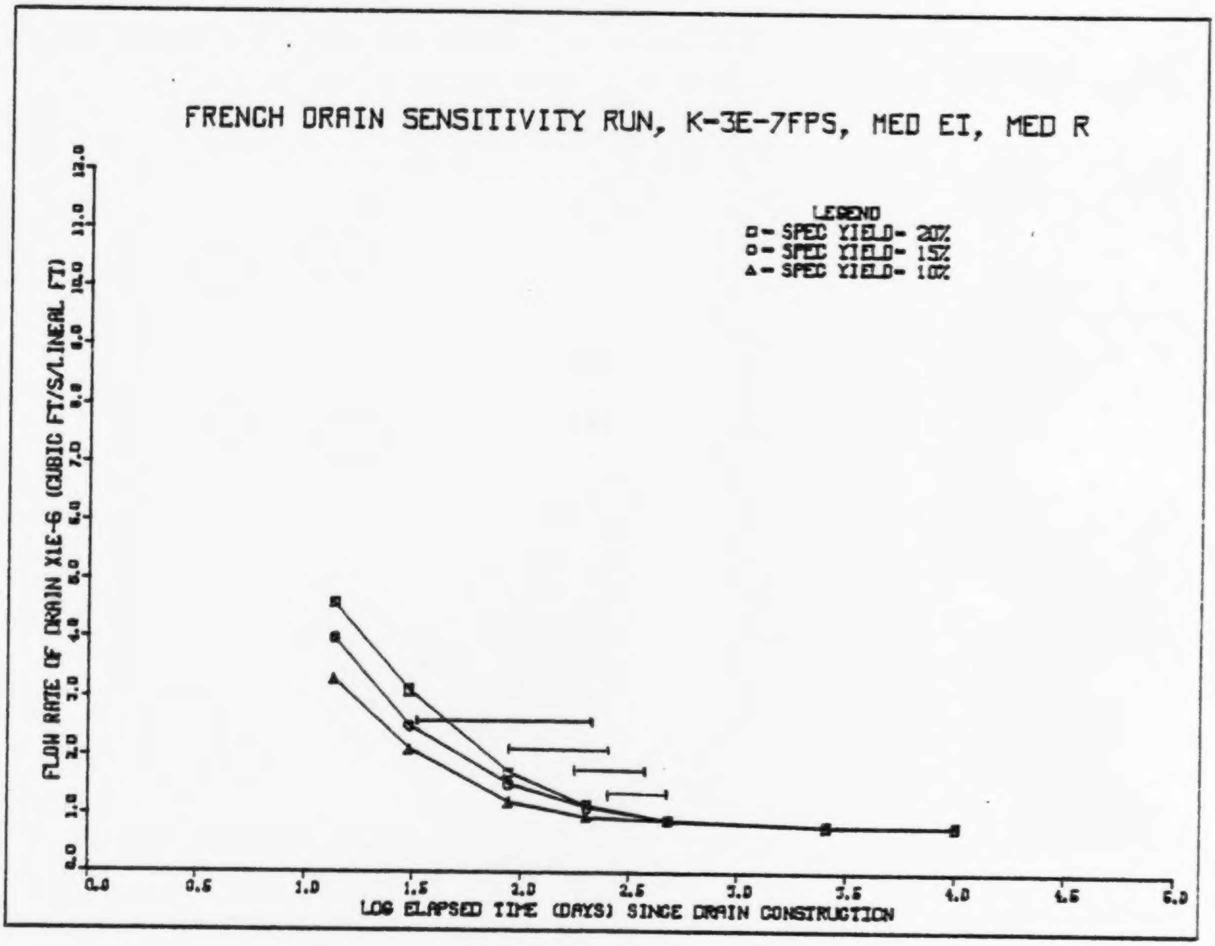

Figure 7.13 Results of sensitivity runs for estimating hydraulic conductivity of the shallow system by history matching the flow rate data collected for the French drain with modeled results based on K of 3×10^{-7} ft/s, medium ET (13 in/yr) and medium recharge (4.9 in/yr). Top curve represents 20% specific yield; middle curve, 15%; and bottom curve, 10%. Brackets represent actual field data collected at Love Canal treatment plant with uncertainty in elapsed time.

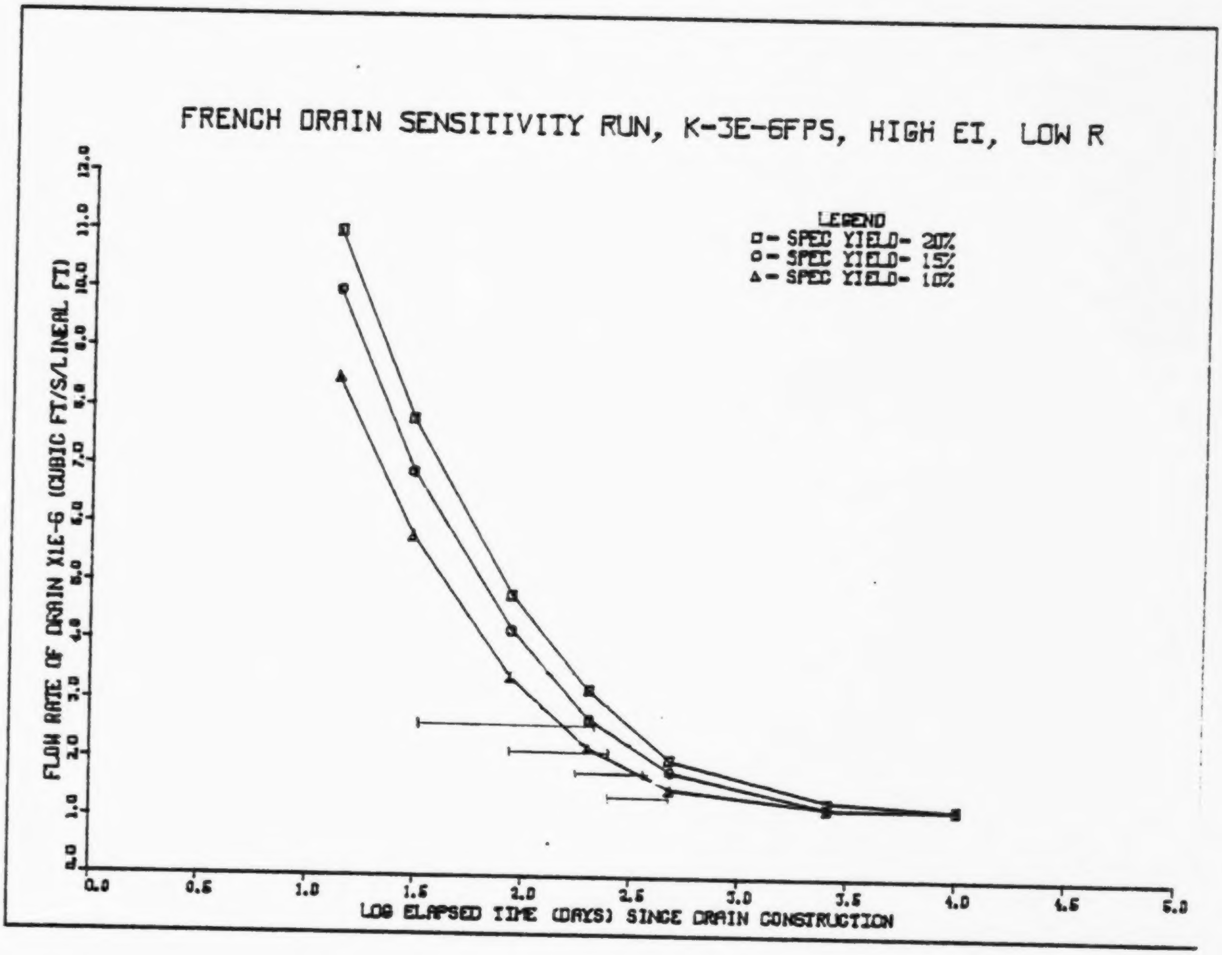

Figure 7.14 Results of sensitivity runs for estimating hydraulic conductivity of the shallow system by history matching the flow rate data collected for the French drain with modeled results based on K of 3 x 10^{-6} ft/s, medium ET (13 ft/s) and medium recharge (4.9 ft/s). Top curve represents 20% specific yield; middle curve, 15%; and bottom curve, 10%. Brackets represent actual field data collected at Love Canal treatment plant with uncertainty in elapsed time.

represents essentially a point estimate. Because of the highly variable nature of the shallow system, it would be very fortuitous if the two estimates agreed.

The shallow system is recognized as a heterogeneous regime. Earth materials of various hydraulic conductivities intersected by the drain could provide results which match the observed data as well as the simplified assumptions represented by Figures 7.11 - 7.14. Thus, Figure 7.15, for example, shows the results of a simulation with not only a drain, but a swale (K of 3×10^{-4} ft/s) and a sand lens (K of 3×10^{-5} ft/s). The shallow system in Figure 7.15 has a K of 3×10^{-7} ft/s just as in Figure 7.11, but the addition of the swale and sand lens effectively increase the flow rate in the drain to a fairly close fit to the observed flow rates. A better match could probably be obtained by adjusting the parameters. However, the information gained from this would be of little value. Without data on flow rates at various points in the drain, any match to observed total flow is nonunique.

7.3.2 French Drain Effects

Section 7.3.1 introduced the design of the French drain model. In that section, analysis of drain flow rates

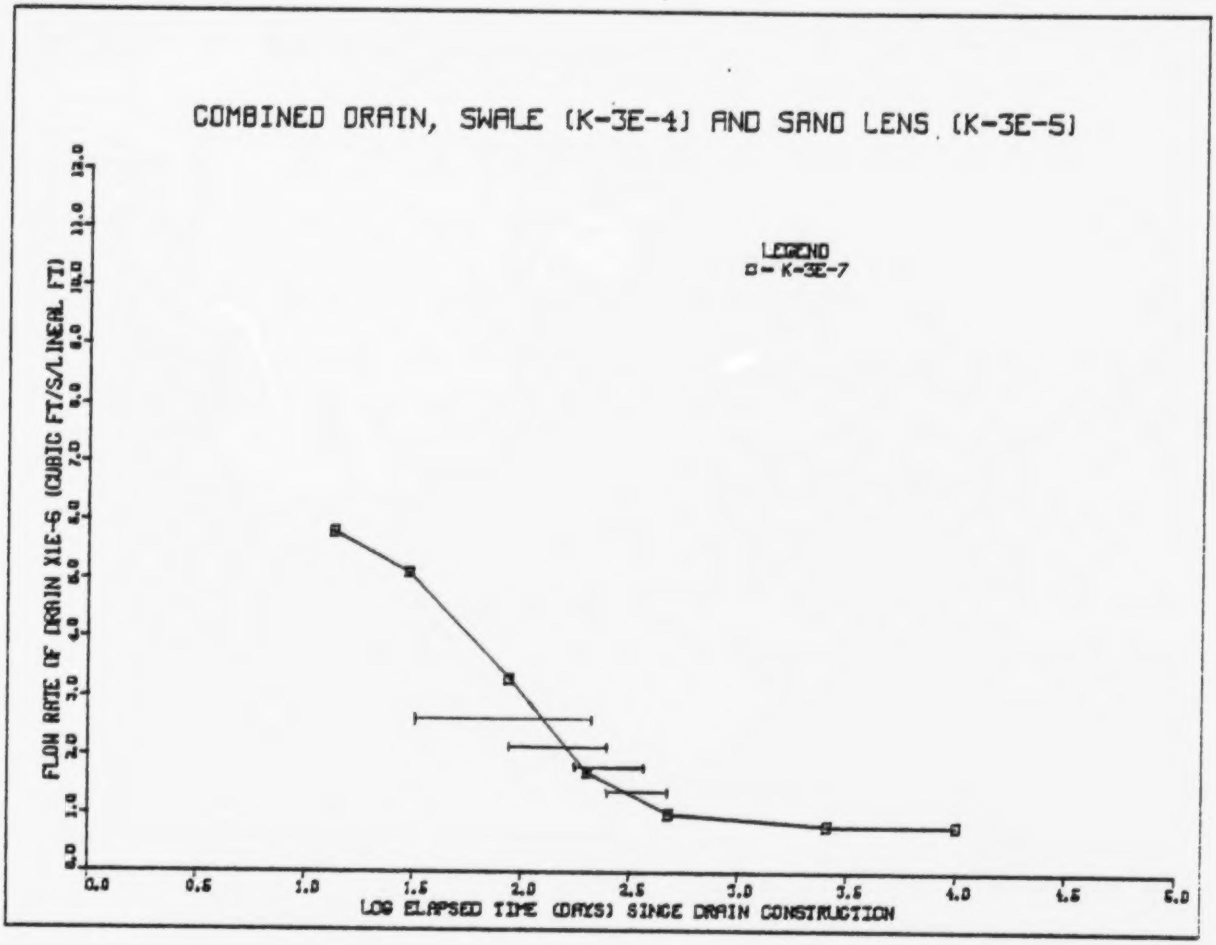

Figure 7.15 Test run on French drain flow rate for shallow system with K of 3×10^{-7} ft/s, swale of 3×10^{-4} ft/s and sand lens of 3×10^{-5} ft/s. Brackets indicate actual field data collected at the Love Canal treatment plant.

to estimate the hydraulic conductivity of the shallow system (Figures 7.11 - 7.15) indicate that the drain should achieve a steady-state condition in about three years, reaching 90% of the steady-state value in about one year. Thus, the shallow system at Love Canal is basically at equilibrium with respect to the French drain, ignoring the seasonal fluctuations in head.

The effects created by the French drain on the shallow system water table are seen in Figure 7.16. The top curve represents the head distribution in the shallow system with a K of 3 x 10^{-6} ft/s. For comparison, the lower curve represents material with a value of K at 3 x 10^{-4} ft/s. In the areas where hydraulic conductivity is 3 x 10^{-6} ft/s, the cone of influence of the drain extends about 180 ft from the drain in a direction perpendicular away from the canal.

In those areas where material with a K of 3 x 10^{-4} ft/s occurs, the cone of influence would extend about 1700 ft from the drain, if highly permeable material extended that far. Thus, in these cones of influence, the French drain would cause a reversal of flow direction back toward the drain.

7.3.3 Clay Cap Effects

A clay cap was incorporated into the shallow system model by specifying higher land elevations in the area above the drains and canal, rows 20 through 27. The thickness of the cap was estimated from the report by

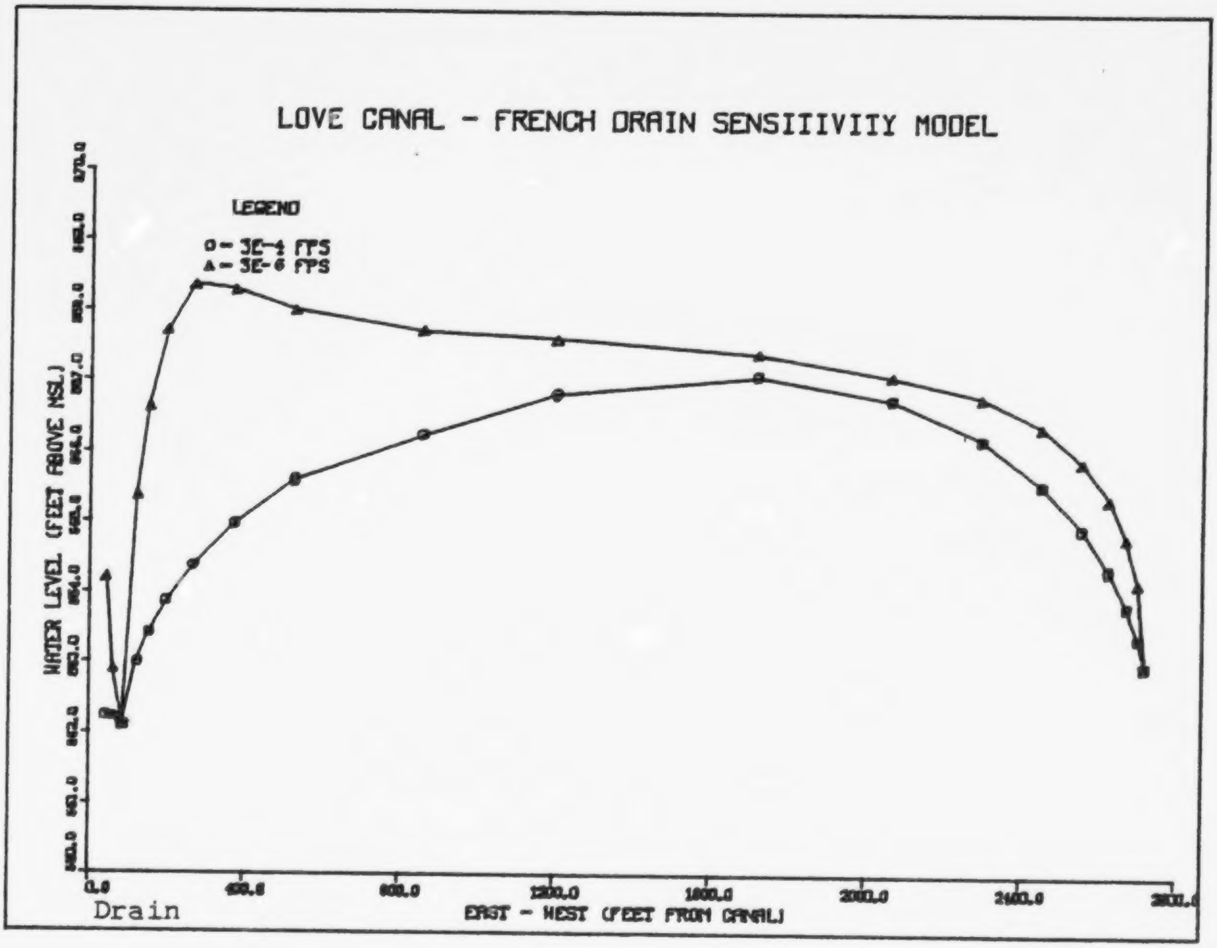

Figure 7.16 Effects of French drain on shallow system water table. Hydraulic conductivity of drain is 3×10^{-5} ft/s. Top curve represents a shallow system with a K of 3×10^{-6} ft/s, and lower curve represents 3×10^{-4} ft/s for comparison.

Clement and Associates (1980). Over the drain, the cap thickness was set at two feet, increasing to five feet at the edge of the canal. The shallow system was assigned a K of 3 x 10^{-6} ft/s, drain K of 3 x 10^{-5} ft/s and specific yield of 15%. Two conditions were created for the cap. It was noted during an on-site visit that the southern sector of the canal had a cap with established vegetation cover, while the northern sector cap was barren of vegetation. Although this section now has vegetation (D. Cogley, oral comm., 1980), this information was not known at the time of this modeling study.

It is hypothesized that the presence of vegetation will increase ET and decrease recharge. On the other hand, the cap devoid of vegetation will have lower ET and potentially higher recharge. Placing these two conditions in the model for the cells containing the clay cap was achieved by increasing recharge by an amount equivalent to the decrease in ET. This was necessary since the model code utilized for this study does not provide for varying ET over the cells, while recharge can be varied. The whole model grid for the shallow system was assigned a high ET of 15.3 in/yr. For the northern part, where ET is theorized to be lower, a recharge of 6.6 in/yr was assigned to effectively decrease ET by approximately 50%. The vegetated southern part of the cap was assigned the same high ET, but was not allowed any increased recharge, being assigned a low value of 2.7 in/yr.

Figure 7.17 displays the results for the clay-cap model. The upper curve in the clay-cap region represents a cross-section through the northern sector while the lower curve is the southern sector. West of the cap, the two sectors have identical water table elevations. This figure illustrates that the clay cap without vegetation conceivably could cause higher water levels inside the drains.

7.4 PREDICTIONS FOR THE SHALLOW SYSTEM

Predictions for the behavior of the shallow system can be made on the basis of results presented in this section. The credibility of these predictions is limited by the lack of sufficient historical data on water levels in the vicinity of the canal. Consequently, the predictions presented here are posed in terms of ranges of likely conditions for assumed ranges in important hydrologic parameters. If a continuing monitoring program is maintained for wells drilled during this and former projects, improved estimates of important hydrologic properties can be obtained. This, in turn, can result in refinement of predictions with less associated uncertainty. Conservative assumptions are used in making these predictions; therefore, attenuation effects (dispersion and sorption) of contaminant concentrations are neglected. Note that neglecting dispersion is conservative with respect to peak height, but not with respect to arrival time. If a less than 50% concentration is a danger, neglecting dispersion actually gives travel times that are too long. The predictions are based on the equation

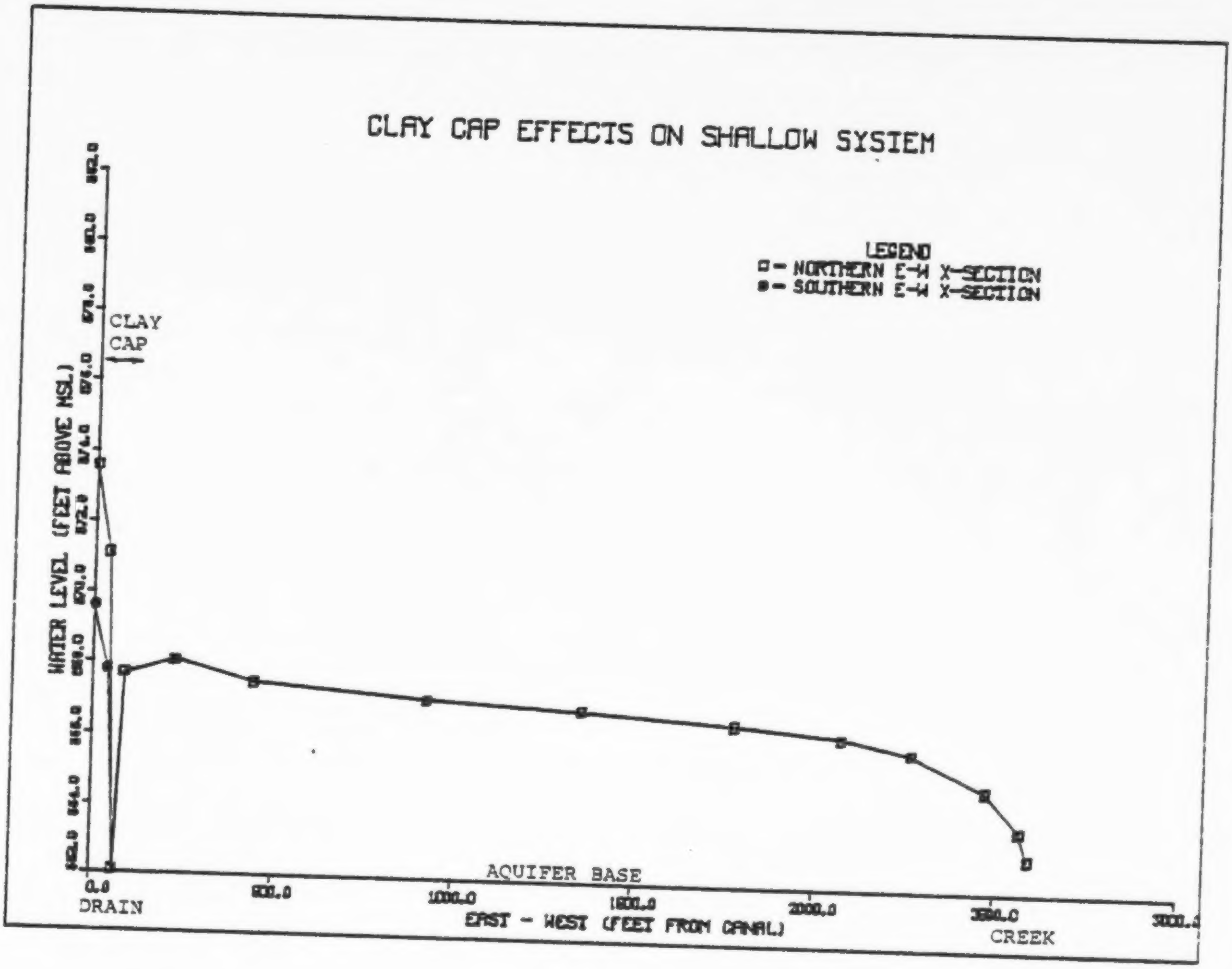

Figure 7.17 Results of the modeling of the clay cap with effects of high ET in the vegetated southern sector and low ET in the barren northern section. Top curve on left represents northern cross sector, while bottom curve represents southern section.

$$v = \frac{K}{\phi}\frac{dh}{dx} \qquad (7.4)$$

where v = interstitial velocity

K = estimated hydraulic conductivity

dh/dx = head gradient provided by the models

ϕ = effective porosity (specific yield).

Equation (7.4) shows that these predictions are sensitive to effective porosity assumptions. For material with K of 3×10^{-4} ft/s, effective porosity is assumed 15%, while for K of 3×10^{-6} ft/s, effective porosity is assumed 10%. The predictions for the shallow system are:

(1) Figure 7.18 provides a graphical representation of travel time versus travel distance for materials of varying hydraulic conductivity. For simplification and ease of comparison, a single effective porosity of 15% was used. These travel times are subsequently discussed in more detail.

(2) The French drain will reverse the ground-water gradient and flow direction out to about 180 ft for material with a K of 3×10^{-6} ft/s and to about 1800 ft for material with a K of 3×10^{-4} ft/s (see Figure 7.16). These values represent the general shallow system and the higher permeability swales, sand lenses or utility trench backfill respectively. Since the drain is approximately 50 ft from the canal, the drain's influence will extend out about 230 and 1850 ft, respectively, from the canal.

(3) In the general shallow system, the area of influence of the French drain will encompass the major portion of ground water which may have been contaminated by subsurface migration over the past 30 years. For example, the area of influence for K of 3×10^{-6} ft/s extends out 230 ft from the canal (see no. 2 above) while the ground water traveled about 34 ft from the canal (assuming an effective porosity of 10%). (See Table 7.4 for ground-water velocities).

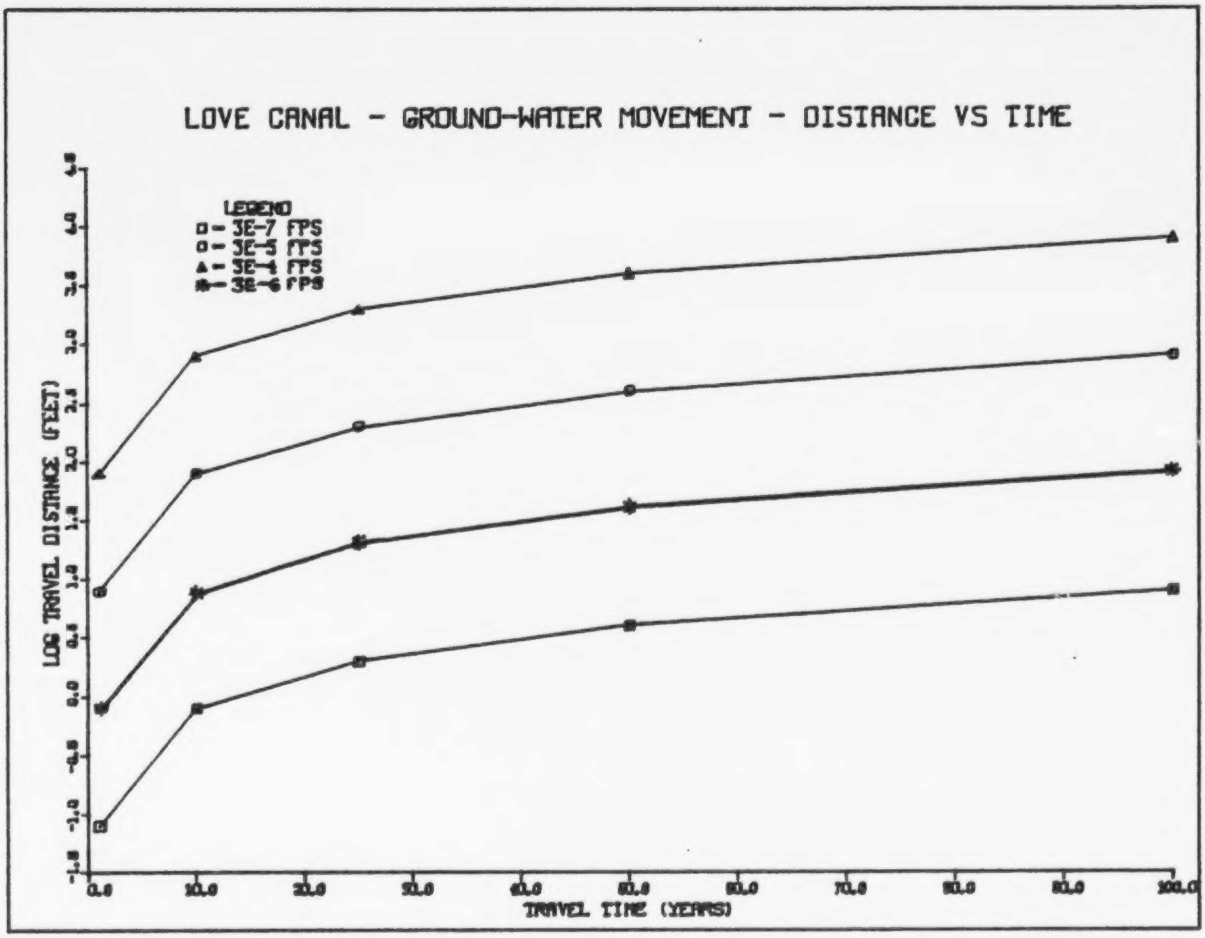

Figure 7.18 Ground-water travel distance versus travel time for earth material of various hydraulic conductivities. Effective porosity is assumed 15%. Top two curves for K of 3 x 10^{-4} and 3 x 10^{-5} ft/s may represent swales or sand lens. Bottom two curves for K of 3 x 10^{-5} and 3 x 10^{-7} ft/s may represent overall shallow system at Love Canal.

(4) In swales, sand lenses, utility trench backfill or other higher permeability zones, the drain's area of influence could extend out 1850 ft (K of 3 x 10^{-4} ft/s) while ground water could have traveled about 1900 ft during the past 30 years (assuming effective porosity of 15%). The drain should cause most of the ground water in these higher permeability zones which could have been contaminated during the past 30 years to begin flowing back toward the drain.

(5) Without the remedial actions taken to date, the ground water in the general shallow system would have migrated up to an additional 6 ft away from the canal in the next 5 years.

(6) With the remedial actions installed to date, the French drain will cause all ground water presently existing between the Canal and drain to be discharged to the drain during the next 5 years. Outside the drain, ground water will flow back to the drain from as far as about 230 ft from the canal during the next 5 years. These predictions assume a general shallow system K of 3 x 10^{-6}ft/s, effective porosity of 10% and gradient of 0.036 obtained from Figure 7.16.

(7) Without the remedial actions, the ground water in material with a K of 3 x 10^{-4} ft/s (effective porosity of 15%) would travel up to an additional 315 feet to a maximum distance of 2215 feet from the canal. The probability of this occuring is unknown, but most likely low because of the discontinuous, heterogeneous nature of the shallow system.

(8) With the remedial actions taken to date, all the ground water in material with K of 3 x 10^{-4} ft/s and effective porosity of 15% between the drain and canal will be discharged to the drain in the next five years. Outside of the drain, all ground water out to a distance of about 900 feet from the canal will be discharged to the drain during the next five years.

(9) Less than 11 years will be required for ground water which originated at the canal 30 years ago to be drawn back to the French drain in material with K of 3 x 10^{-4} ft/s and effective porosity of 15%. This disregards attenuation effects on contaminants and assumes maximum travel distance of 1900 feet from the canal over 30 years.

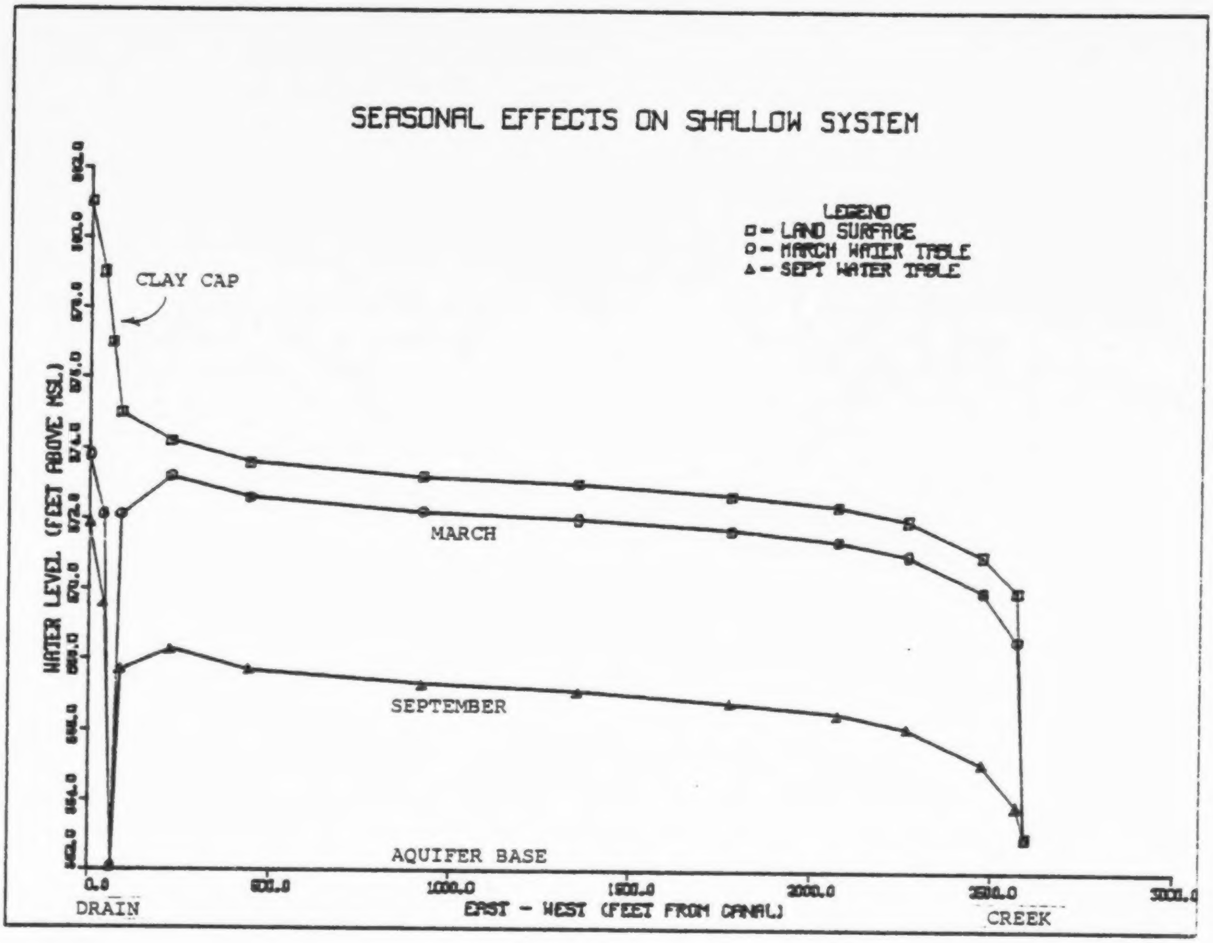

Figure 7.19 Seasonal effects on water level of the shallow system as seen in cross section.

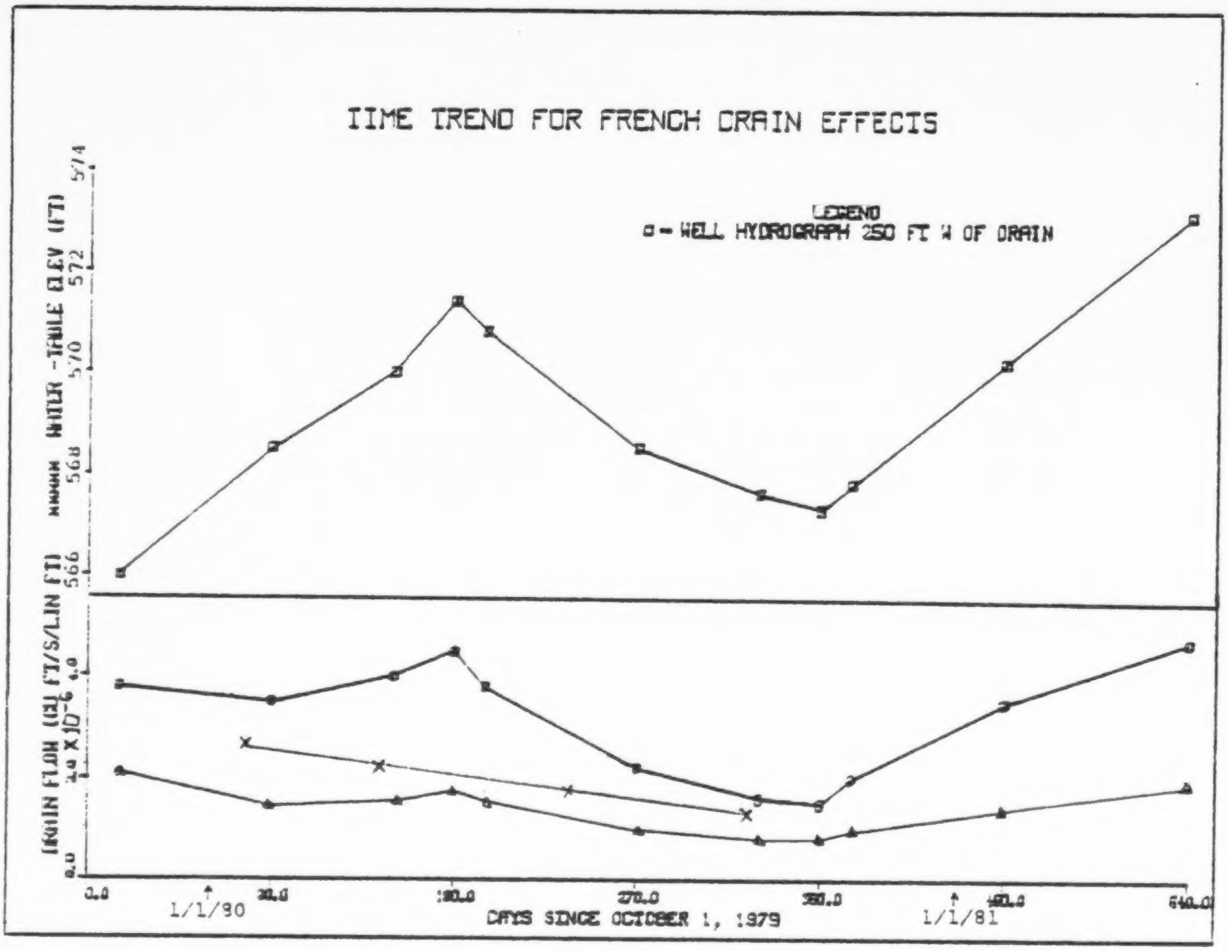

Figure 7.20 Trends over time for water levels in a hypothetical well 250 ft west of drain and flow rates in the drain. Upper flow rate curve represents a K for shallow system of 3 x 10^{-6} ft/s and 10% specific yield. Lower flow rate curve represents K of 5 x 10^{-7} ft/s and 15% specific yield. Middle flow rate curve (x) represents observed data.

(10) Establishing vegetation on the northern-sector clay cap should cause lowering of the water table by increasing evapotranspiration (see section 7.3.3) as has probably occurred in the southern section.

(11) Seasonal effects on the shallow system and remedial actions will cause a lowering of the water table over the summer and raise the water table during the late fall and early spring. Figure 7.19 represents a cross-section showing the low September and high March water-table levels, with variation of about 4 feet. Figure 7.20 shows a hypothetical well hydrograph and associated French drain flow rates over time, beginning October 1, 1979 and extending into 1981. With a simplified two season model, the hydrograph illustrates the water table highs that occur in early spring and the lows in late summer. Paralleling the water-table level changes, the drain flow rates have declined over the past summer and closely match the observed values. Drain flow rates are expected to increase again in early spring to a high of between 2×10^{-6} and 4.5×10^{-6} ft/s/lineal ft.

7.5 SUMMARY OF THE SHALLOW SYSTEM ANALYSIS

Based on the assumptions and simplified models presented in this chapter on the analysis of the shallow system at Love Canal, the following general conclusions are made:

(1) Over the past 30 years, ground water could have migrated about 35 ft from the canal in the less permeable material (K of 3×10^{-6} ft/s and effective porosity of 10%). For higher permeability material (K of 3×10^{-4} ft/s and effective porosity of 15%), over the past 30 years ground water could have migrated up to 1900 ft from the canal. Considering the discontinuous and heterogeneous nature of the shallow system, the actual distance of ground water migration will lie between these extremes with a much lower probability of the greater distance.

(2) Based on history matching of the French drain flow data, the shallow system may be characterized as having averaged hydrologic properties with a bulk hydraulic conductivity of 3×10^{-6} to 3×10^{-7} ft/s (10^{-4}-10^{-5} cm/s) and effective porosity of 10-15%.

(3) Although the clay sediments in the shallow system are considered to have a low permeability, much smaller than the silty sands, fissured zones which occur in the clays can impart a higher permeability closer to that of the silty sands.

(4) The French drain is an effective remedial action to prevent further migration of contaminants in the shallow system away from the drain. No contaminated ground water in the less permeable material (K of 3×10^{-6} ft/s) would have traveled further than the drain in the past 30 years where the drain is at least 35 feet from the canal.

(5) The French drain will cause most ground water(which has migrated through high permeability pathways) beyond the drain in the past 30 years to reverse flow back to the drain.

(6) Since ground-water movement in the general shallow system is slow, migration of contaminants from the canal to nearby residences must have occurred through zones

of higher permeability such as swales, sand lenses or utility trench backfill, or occurred through overland flow across ground surface or from burial of waste much closer to residences than previously suspected.

(7) Based on modeling results and knowledge of the shallow system, there is a low probability of subsurface migration of contaminants from the canal beyond the first circle of residences except in isolated high permeability zones. If contamination is found outside the first circle of homes, the contamination may be due to other than solely subsurface migration.

(8) Availability of data collected on a continuing basis of one to three years would allow refinement of predictions and conclusions. With the additional data then available, more detailed ground-water flow and solute transport models would be applicable.

References

Apps, J.A., Lucas J., Mathur, A.K. and Tsao, L., 1977, Theoretical and experimental evaluation of waste transport in selected rocks: 1977 annual report of LBL Contract No. 45901 AK: Lawrence Berkeley Laboratory, Berkeley, CA., Report LBL-6022, 139 pp.

Becker, P.L., 1979, Aerial survey toxic chemcial disposal site, Niagara Falls, New York, area, June 27, 1979 Volume I, Lockheed Electronics Company, Inc., EPA Contract EPA68-03-2636.

Bouwer, H., 1978, Groundwater Hydrology, McGraw-Hill Book Company, New York, 480 p.

Brunner, D.R. and D.J. Keller, 1972, Sanitary Landfill Design and Operation, U.S. EPA Report SW-65ts, 59 p.

Bureau of Reclamation, 1949, Theory of falling head permeameter in unsaturated material, memorandum to C.W. Jones from D.H. Jarvis.

Bureau of Reclamation, U.S. Dept. of Interior, Ground Water Manual, 480 p., 1977, U.S. G.P.O.

Clark, S.P., Jr., 1966, Handbook of Phsysical Constants, revised edition, Geological Society of America Memoir 97, 587 pp.

Clement Associates, Inc., 1980, The remedial construction project at Love Canal, Niagara Falls, New York: Finding and comments, prepared for Department of Transportation, State of New York, 115 p.

Conestoga-Rovers & Associates, 1978, Project Statement Love Canal Remedial Action Project, City of Niagara Falls.

Conestoga-Rovers, 1979, Love Canal monitoring well data, preliminary hydrogeological data. In letters to S. Lester, October 12, 1979.

Cooper, H.H., J.D. Bredehoeft, and I.S. Papadopulos, 1967, Response of a finite diameter well to an instantaneous change of water, Water Resources Res., vol. 3, no. 1, pp. 263-269.

Domenico, P.A., 1972, Concepts and models in groundwater hydrology, McGraw-Hill, New York, 405 p.

Earlougher, R.C., Jr., 1977, Advances in well test analysis, Soc. of Pet. Eng. Monograph vol. 5, Henry L. Doherty series, 264 p.

Ebert, C.H.W., March 7, 1979, unpublished memo dated 3/7/79 entitled: Comments on the Love Canal Pollution Abatement Plan (no. 3), Department of Geography, SUNY at Buffalo.

Ferris, J.G., and D.B. Knowles, 1954, The slug test for estimating transmissibility, U.S. Geol. Survey Ground Water Note 26.

Fetter, C.W., Jr., 1980, Applied Hydrogeology, Merrill Publishing Company, Columbus, 488 p.

Freeze, R.A., 1975, A stochastic conceptual analysis of one-dimensional ground-water flow in nonuniform homogeneous media, Water Resources Research, v. 11, p. 725-741.

Freeze, R.A. and J.A. Cherry, 1979, Groundwater, Prentice-Hall, Englewood Cliffs, N.J., 604 p.

Glaubinger, R.S., P.M. Kohn, and R. Remírez, 1979, Love Canal aftermath, Chemical Engineering, p. 86-92.

Gringarten, A.C. and H. J. Ramey, Jr., 1974, Unsteady-state pressure distributions created by a well with a single horizontal fracture, partial penetration, or restricted entry, Soc. Pet. Eng. J., 413-426, AIME, p.257.

Hantush, M.S., 1964, Hydraulics of wells: in Advances in Hydroscience, V.T. Chow, ed., New York, Academic Press, p. 281-432.

Fred C. Hart Associates, Inc., 1978, Draft Report: Analysis of a ground-water contamination incident in Niagara Falls, New York, Prepared for: U.S. EPA, Contract No. 68-01-3897.

INTERCOMP, 1976, A model for calculating effects of liquid waste disposal in deep saline aquifers, Part I -- development, U.S. Geol. Surv. Water-Resources Investigations 76-61.

Jacob, C.E., 1950, Flow of ground water, in H. Rouse (ed.), Engineering Hydraulics, John Wiley & Sons, Inc., New York, pp. 325-386.

Johnson, A.I., 1967, Specific Yield - Compilation of Specific Yields for Various Materials, U.S.G.S. Water Supply Paper 1662-D, 74 p.

Johnston, R.H., 1964, Ground WAter in the Niagara Falls area, New York, State of New York Conservation Department Water Resources Commission Bulletin GW-53, 93 p.

JRB Associates, 1980, Hydrogeology of the Love Canal area, draft final report, submitted to GCA Corp.

Larson, S.P., 1978, Direct solution algorithm for the two-dimensional ground-water flow model. U.S. Geol. Surv. Open-File Report 79-202, 22 p.

Leonard, R.P., P.H. Werthman and R.C. Ziegler, 1977, Characterization and abatement of ground-water pollution from Love Canal chemical land fill, Niagara Falls, N.Y., Calspan Report No. ND-6097-M-1.

McGuinness, C.L., 1963, The Role of Ground Water in the National Water Situation, U.S.G.S. Water Supply Paper 1800, 1121 p., 4 plates.

Miller, D.H., 1977, Water at the Surface of the Earth, International Geophysics Series, Vol. 21, Academic Press, New York, 557 p.

National Oceanic and Atmospheric Admin. (NOAA), 1978-1979, Climatological Data -- Annual Summary, New York, Vol. 90, no. 13, 1978, Vol 91, no. 13, 1979.

Owens, D.W., 1979, Soils report, northern and southern sections - Love Canal, Attachment VIII to Earth Dimensions Report.

Pinder, G.F., and J.D. Bredehoeft, 1968, Application of the digital computer for aquifer evaluation: Water Resources Research, v. 4, no. 5, p. 1069-1093.

Power Authority of the State of N.Y. (PASNY), 1965, Niagara Power Project Data Statistics, 48 p.

Price, H.S., and K.H. Coats, 1974, Direct methods in reservoir simulation: Soc. Petrol. Eng. Jour., June 1974, p. 295-308.

Ralston, A., and H.S. Wilf, 1967, *Mathematical methods for digital computers*, Volume II, John Wiley & Sons, Inc., New York, 287 p.

Theis, C.V., 1935, The relation between the lowering of the piezometric surface and the rate and duration of discharge of a well using ground-water storage, Trans. Amer. Geophys. Union, vol. 2, pp. 519-524.

Trescott, P.C., G.F. Pinder, and S.P. Larson, 1976, Finite-difference model for aquifer simulation in two dimensions with results of numerical experiments, Techniques of Water-Resources Investigations of the United States Geological Survey, Book 7, Chapter C1, 116 p.

U.S. Department of Agriculture, 1972, Soil Survey of Niagara County, New York, U.S. Government Printing Office 1972 0-459-901.

Walton, W.C., 1970, *Groundwater resource evaluation*, McGraw-Hill Book Co., New York, 664 p.

Winograd, I.J., and W. Thordarson, 1975, Hydrogeologic and hydrochemical framework, South-Central Great Basin, Nevada-California, with special reference to the Nevada Test Site: U.S. Geol. Survey Professional Paper 712-C, pp. C1-C126.

FINAL REPORT ON
GROUND-WATER FLOW MODELING STUDY
OF THE LOVE CANAL AREA, NEW YORK

APPENDICES A-D

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A-D-i

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APPENDIX A. MATHEMATICAL SIMULATION OF HIGH PH WATERS

While at the Love Canal site, Charles Faust contacted Dr. F. J. Pearson, a geochemist on our external QA team, to explain anomalously high pH readings reported in some of the wells. He suggested that the high pH readings could be the result of cement in the wells. To further verify this conclusion, Dr. Pearson made a series of computer simulations using geochemical reaction models. His results show that pH conditions as high as 12.4 can occur in wells containing curing cement. A memorandum from him on this topic in included as Appendix A.

Dr. Pearson simulated the behavior of the water if potassium hydroxide (KOH) were to dissolve in it as well as cement. His simulation shows that KOH solution increases the pH to values higher than possible from cement solution alone. As his figure shows, though, dissolved potassium measurements would be more sensitive indicators of KOH solution than would pH measurements. Completed chemical analysis is necessary before conclusive determinations can be made. If the high pH is a result of the cement, the length that the effect would persist is a mass balance problem, which was not addressed in this memorandum, and cannot be addressed without additional data.

MEMO

TO: C. R. Faust, GeoTrans

FROM: F. J. Pearson, INTERA

DATE: October 15, 1980

RE: Love Canal: Mathematical Simulation of High pH Waters

BACKGROUND

On Monday, October 13th, we discussed by telephone the high pH waters found in some of the Love Canal test wells. You mentioned that KOH was reported to have been in some of the barrels disposed of in Love Canal, and that the high pH values were being taken as evidence of the presence of this KOH in the water at the several wells. You said that you were not happy with this explanation because the presence of waste material in some of the high pH wells would violate your concept of the ground-water flow pattern in the area. You therefore wanted to explore what other mechanism might be responsible for waters with pH values of 11 and above.

My reply was that, in the absence of certain unusual mineral deposits or types of hot spring activity, ground-water pH values above about 10 generally result from the presence of fresh cement. You responded that because all the samples in question were taken from freshly cemented wells, this could well be the case. You questioned, though, whether cement could account for pH values of greater than 13. Based on a rough hand calculation, I guessed that cement solution should not lead to pH values much greater than 11 or 12, agreeing with a value of 12 which you said had been measured in fresh cement. The question then became one of estimating as closely as possible what the highest cement-caused pH was likely to be, so that samples of higher pH values could be accepted as containing some stronger base such as KOH. I offered to mathematically simulate the composition of a water reacted with fresh cement, and to simulate further the compositions resulting from the addition of varying amounts of KOH to such a water. This memorandum reports the results of these simulations.

SIMULATION MODELING

The simulations were made using INTERA's version of the code PHREEQE, which was developed by Parkhurst, Plummer and Thorstenson, U. S. Geol. Survey, Reston. The aqueous speciation routine of PHREEQE uses an ion association model, and arbitrary reaction steps can be taken and/or phase boundaries solved for directly, using a combination of charge and mass balance equations. The thermodynamic data base used was that suggested by Parkhurst, et al., except that data for solid $Ca(OH)_2$, the mineral portlandite, and solid KOH taken from Robie et al., (1978, U. S. Geol. Survey Bull. 1452) were added for these simulations.

The component of fresh cement with greatest effect on pH is $Ca(OH)_2$ which dissolves in water according to the reaction:

$$Ca(OH)2 = Ca^{+2} + 2OH^-$$

The cement reaction simulated was an idealized one in which only the effect of $Ca(OH)_2$ dissolution was considered. The remaining components of cement are complex alumno-silicate materials which are unlikely to modify the effect of the $Ca(OH)_2$ reaction by more than a 1/10 pH unit, at least on the time scale of interest (weeks).

I have no data on representative background water compositions in the Canal region, so I assumed as a starting composition that of a pure water in equilibrium with Ca CO_3 (calcite) at a CO_2 pressure P_{CO_2}) of 10^{-2} atmospheres. Such a composition is common in water at shallow depths in sedimentary formations.

This water was (mathematically) brought to equilibrium with $Ca(OH)_2$ to simulate the reaction between background water and fresh cement. Then to this $Ca(OH)_2$ saturated water, KOH was (mathematically) added in increasing amounts, and the increase in pH and dissolved K^+ content and the decrease in Ca^{+2} noted. (The CA^{+2} decrease results from the driving to the left of the reaction above as OH^- from KOH is added to the solution.)

RESULTS

The simulation results are displayed in the attached figure, in which pH on the lower horizontal axis is plotted against molality (moles/kg H_2O) of dissolved cation on the left vertical axis. The right vertical axis gives solute cation concentrations in parts per million (mg/kg). The moles to mass conversion factors for both cations are nearly the same because of the similarity of their atomic weights ($K^+ = 39.10$; $Ca^{+2} = 40.08$).

The composition at Point A on the figure is that of $Ca(OH)_2$ saturated water, and represents the maximum effect of fresh cement alone on the water. The pH calculated in this simulation was 12.4 and the dissolved Ca^{+2} concentration 0.02 molal (800 ppm).

Points to the right of Point A show the K^+ (squares) and Ca^{+2} (circles) contents and pH's of solutions resulting from the addition of the amounts of KOH shown along the top to solution A.

The smallest amount of KOH (mathematically) added to the $Ca(OH)_2$ saturated solution A was 0.56 gm/kg H_2O (10^{-2} moles KOH). This addition raises the pH only marginally (to 12.5 from the solution A value of 12.4), but the resulting 10^{-2} moles (390 ppm) of K^+ in solution is far above that usually found in ground waters in regions like that of Love Canal. Normal ground-water K^+ contents in such regions are less than 10 ppm. Thus the presence of small amounts of KOH in the Love Canal area ground-waters are likely to be most easily detected by observations of elevated K^+ contents.

The addition of larger amounts of KOH will continue to increase the K^+ content, but will also noticeably increase the pH. A solution which contains 28.0 gm KOH per kg H_2O, for example, will have a pH of 13.5, but will also contain 0.5 moles (20,000 ppm) of K^+.

In using these results and communicating them to others, remember and stress that they are idealized and that while the general trends shown are correct, the details in the field may be different. For example, the pH of cement-containing water may be anywhere between the ambient pH and that of a $Ca(OH)_2$ saturated solution, depending on the mixing ratio. The pH of the $Ca(OH)_2$ saturated solution itself may be several tenths to perhaps 0.5 pH units different from the 12.4 units calculated depending on the presence of other minerals and possibly on the availability of CO_2 in any gaseous phase prsent as well. The relationship between K^+ and pH resulting from KOH addition may not be exactly as simulated, either. If sufficient gas phase CO_2 is present, the pH may be decreased by reaction between dissolved CO_2 and OH^-. This would shift K^+ vs pH points to the upper left of the theoretical line of the figure. On the other hand, exchange reactions between K^+ and other cations held on the solid aquifer matrix could occur. This would lower the K^+ content and produce field K^+ vs pH values to the lower right of the line of the figures. Neither the possible CO_2 or exchange reactions would be likely to obscure the essential correspondence between pH values of 13 and above with high K^+ contents, if KOH is indeed present in the high pH waters sampled.

SUGGESTED ADDITIONAL WORK

The simulation modeling described here is based on highly idealized water and solute compositions, and it would be well to repeat it using chemistries more representative of actual Love Canal area ground waters. I should like to have analyses to be used as the basis of geochemical simulation modeling of the Love Canal region include:

D

Temperature
Field and laboratory pH
Titrated alkalinity
Total organic carbon and total inorganic carbon. (Total organic carbon is most probably determined as the difference between measured total carbon and measured total inorganic carbon, so the latter value should be available and not require additional analysis.)
Common cations, at a minimum Na^+, K^+, Ca^{+2}, and Mg^{+2}.
Common anions, at a minimum Cl^- and SO_4^-, in addition to the alkalinity, above.

The analyses should balance in charge to within better than 5-10%. A larger imbalance suggests either an analytical error or the presence of some important but unanalyzed dissolved species.

Analyses of the full range of water types should be available. It is extremely important that there be included several anlyses of waters which in your best hydrologic judgement represent the ambient typical areal ground-water chemistry. This ambient water is the base on which representative simulations are based, so the importance of good background analyses cannot be overstressed.

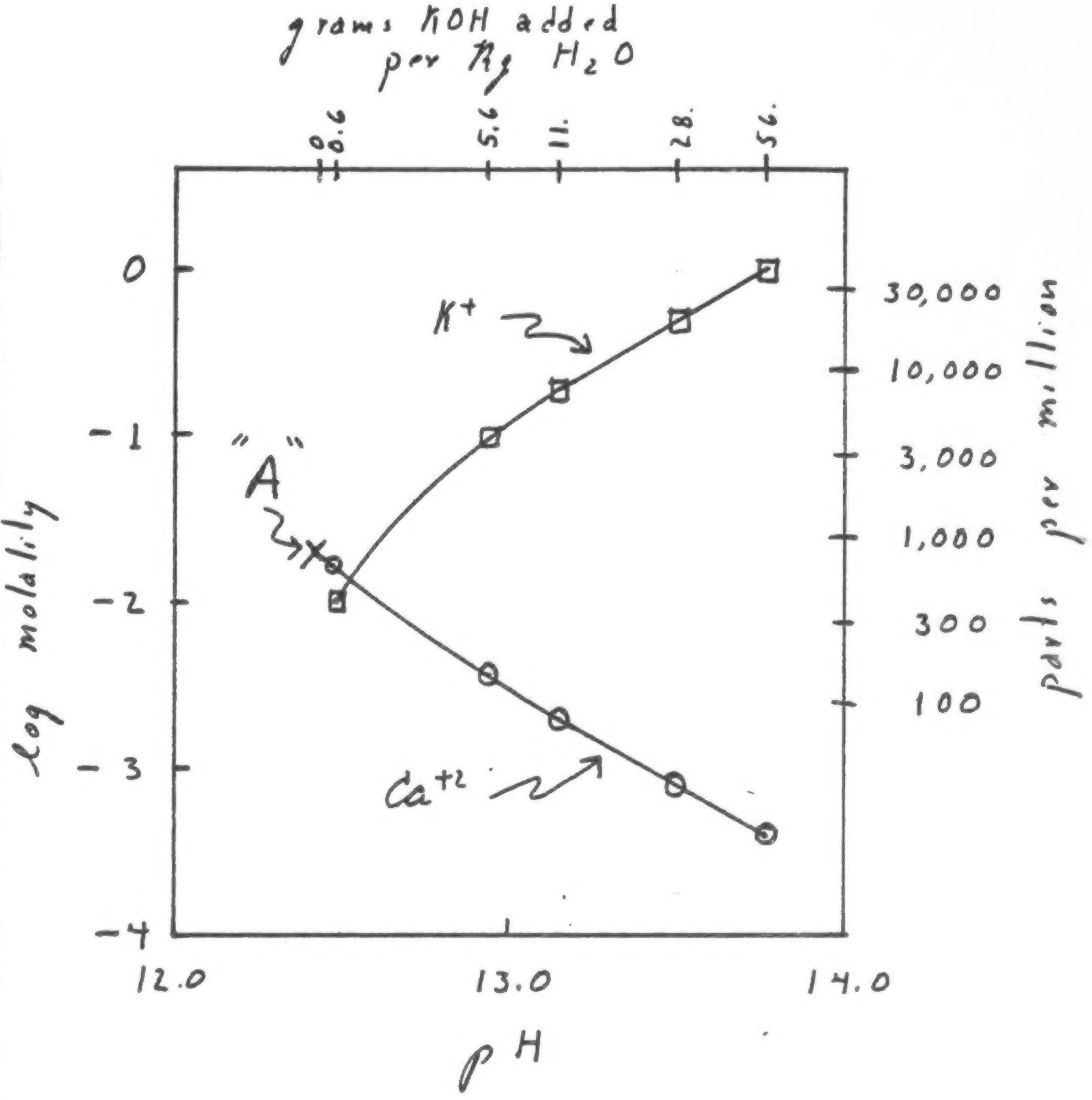

Figure to accompany Pearson's memo to Faust, 15-Oct-80, re high pH Love Canal waters.

APPENDIX B. AQUIFER TEST PROCEDURES

As part of a memorandum dated 2 September 1980, GeoTrans outlined aquifer test procedures based on our limited knowledge of the Love Canal hydrology. These procedures were suggested at the beginning of the drilling program before any tests had been performed. This discussion is included as Appendix B.

Well Test Sensitivity Analysis and Discussion of Results. Three types of well tests are considered in this analysis:

- slug tests
- constant discharge tests in fully penetrating wells
- constant discharge tests in partially penetrating wells in an anisotropic aquifer

Slug tests: Slug tests or falling-head tests provide a method for determining field transmissivities from single wells. The test involves quickly injecting a known volume of water into a well and measuring the water-level responses. A critical factor in performing these tests is the timing of water-level measurements. This timing is controlled primarily by the type of material tested. Highly permeable units will approach static (pre-slug) levels quickly (in a few seconds) while lowly permeable units will respond slowly (in terms of days or months). To provide an estimate of test duration, a sensitivity analysis for the geological units at the Love Canal site was conducted.

The analytical solution that describes the response of a finite-diameter well to an instantaneous charge of water is given by Cooper et al. (1967). The solution for a line source (infinitely small diameter) is given by Ferris and Knowles (1954). The line source solution is valid only for relatively large times (after the slug is applied). So, in this analysis the finite-diameter solution was used. The solution is described in detail in the cited reference, a copy of which is enclosed with this memorandum.

Typical values of important parameters were used for the analysis of the unconsolidated sediments. Extreme values (high and low) were chosen for the water-bearing units of the Lockport dolomite. These values are given in table 1. The results of the calculations are shown in figures 1 and 2. As may be seen in figure 1, the wells in the sand are anticipated to respond in terms of minutes and the wells in the clay and till will respond in terms of days. Actually, the response in the wells in clay or till may be even slower, as relatively high values of hydraulic conductivity were used in the calculations. For determining field parameters, water-level measurements should be timed in a logarithmic sequence, e.g., 2 sec., 4 sec., 8 sec., 16 sec., 30 sec., 1 min., 2 min., 4 min., 8 min., 16 min., 30 min., 1 hr., etc. For the bedrock wells, we expect that the lowly permeable water-bearing zones will respond in a range of a few minutes to hours. The more permeable dolomite zones will respond in terms of seconds. For these zones slug tests may not provide estimates of transmissivity. Results for the dolomite are given in figure 2.

Table 1. Data used in slug test calculations, T = transmissivity, S = storage coefficient, K = Hydraulic conductivity, b = thickness, and r = well radius.

	T	S	K	b	r
Sands	8 ft^2/d	.1	1 ft/d ($3.5x10^{-4}$ cm/s)	8 ft	.167 ft
Clays and Tills	.02 ft^2/d	.001	.00133 ft/d ($4.7x10^{-7}$ cm/s)	15 ft	.167 ft
Low-T Dolomite	10 ft^2/d	10^{-4}	1 ft/d ($3.5x10^{-4}$ cm/s)	10 ft	.167 ft
High-T Dolomite	1000 ft^2/d	10^{-4}	100 ft /d ($3.5x10^{-2}$ cm/s)	10 ft	.167 ft

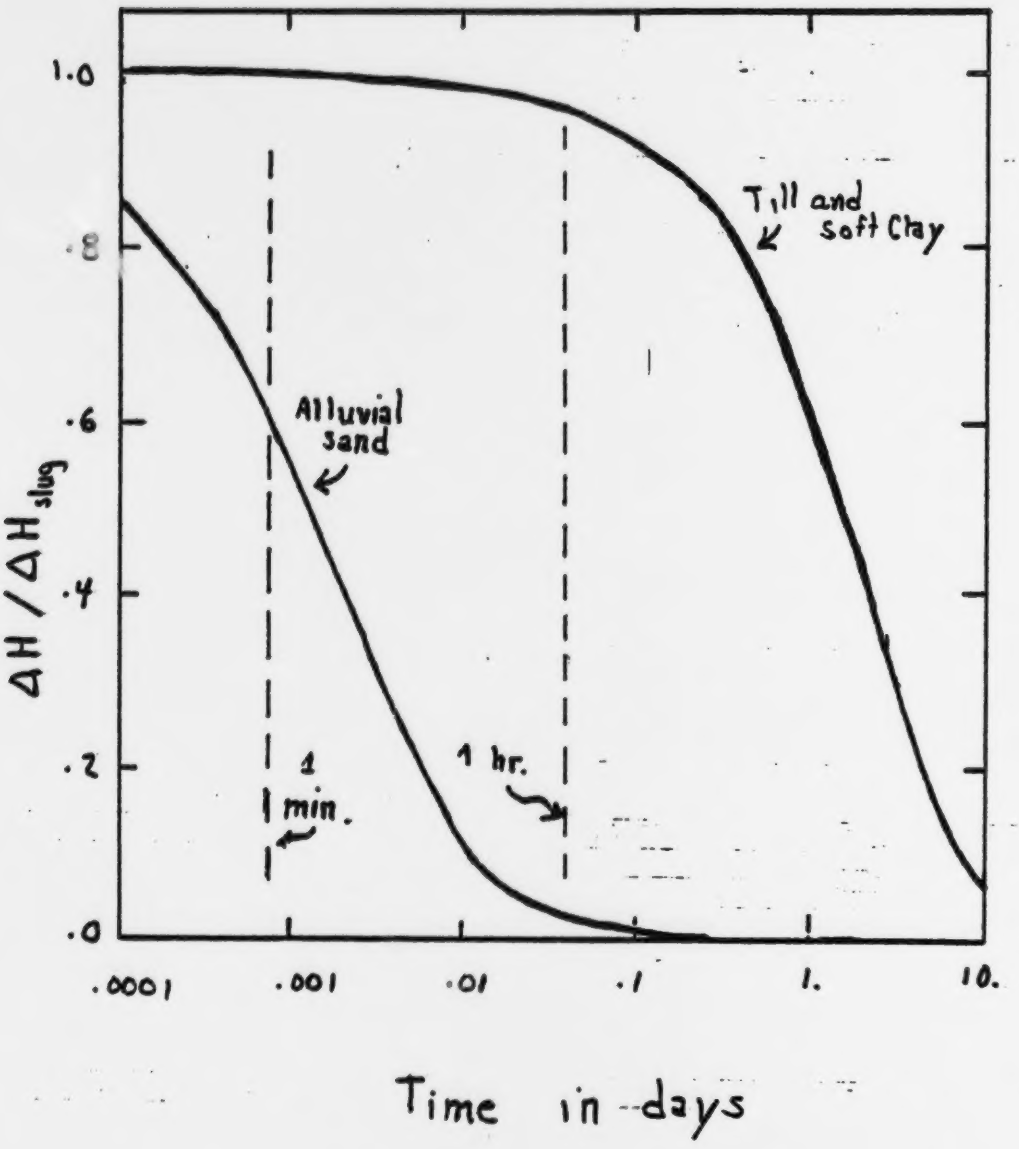

Figure 1. Response of water levels to slug tests for typical sands, clays and tills; ΔH = head at time t minus the head before slug injected, ΔH_{slug} = head at time slug is injected minus the head before slug is injected.

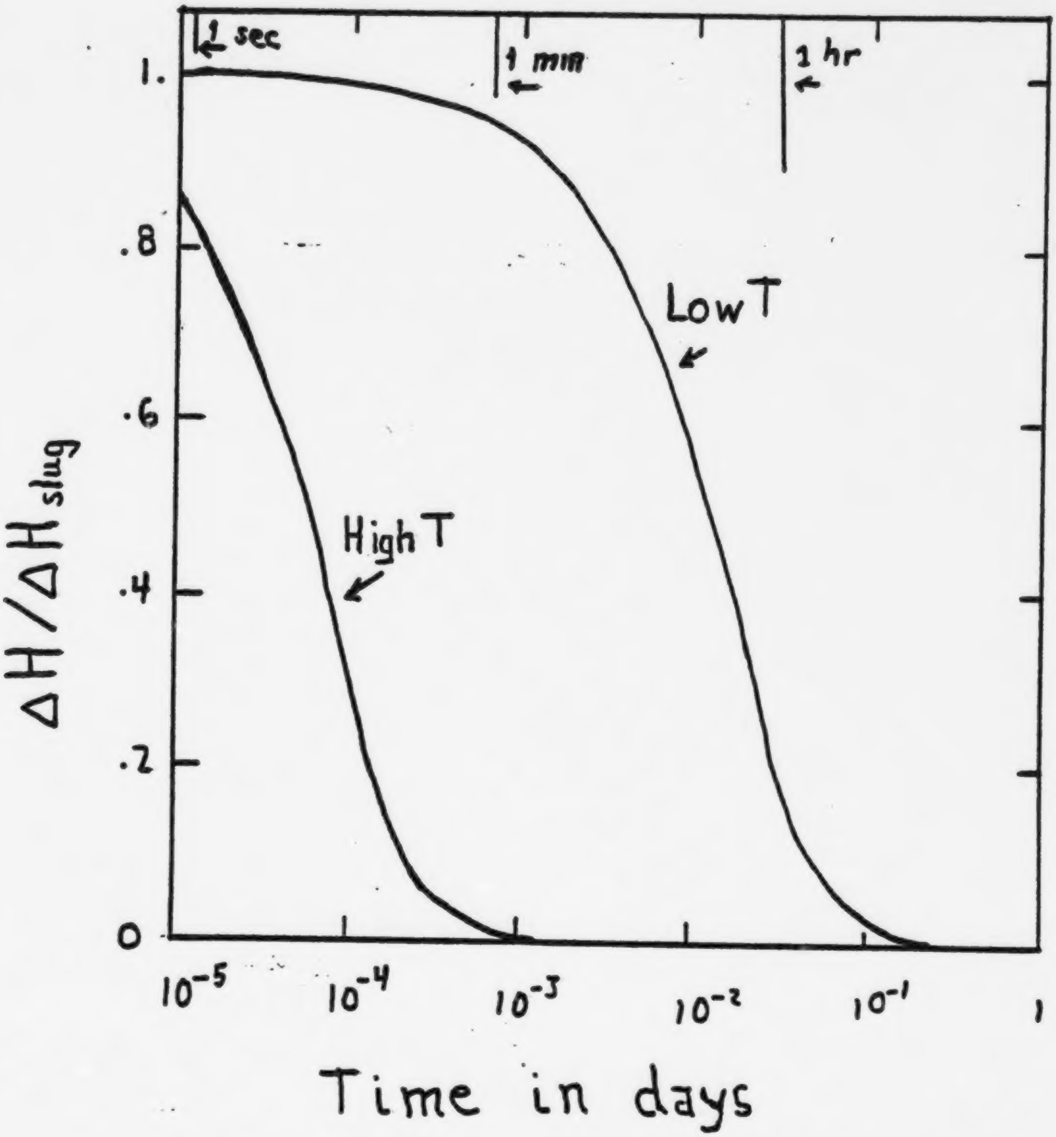

Figure 2. Response of water levels to slug tests for high and low transmissivity water-bearing zones in the dolomite; ΔH, ΔH_{slug} are defined in figure 1.

Fully penetrating wells in dolomite: Constant discharge tests in wells completed in the Lockport Dolomite could provide estimates of transmissivity and storage coefficients. A single well test would involve pumping the well at a constant rate; observing the water-level decline in the well during the period of the test (one to two days); shutting the pump off; and observing the water-level recovery in the well. Important considerations for designing this test are anticipated water-level declines and pumping rates. One does not want water-level declines to be too small to measure, nor does one want to cause excessive declines. A simple analysis using the Theis equation (see, for example, Hantush, 1964) was used to determine pumping rates required for a given desired drawdown at the end of one day of pumping. Using this equation, it was possible to estimate required pumping rates for different values of transmissivity. If slug tests are used to obtain an initial estimate of transmissivity, the appropriate pumping rates can be determined from the equation described in the next paragraph.

The solution for drawdown at a distance r from a constant discharge line source which is fully penetrating a homogeneous aquifer is given by the Theis equation. For $u = \frac{r^2S}{4Tt} < .05$ where S is the storage coefficient, T is transmissivity and t is time, Theis' equation may be approximated by $s = \frac{Q}{4\pi T}(-.5772-\ln u)$, in which s is the drawdown and Q is the discharge rate (Hantush, 1964). This equation may be rearranged so that $Q = \frac{s4\pi T}{(-.5772-\ln u)}$. If we desire to know the required discharge rate to attain a specified drawdown at a given time after pumping starts, the above equation provides the estimate. Figure 3 shows the required pumping rates to achieve a drawdown of 10 feet in a 4 inch well after 1 day of pumping where the storage coefficient is assumed to be 10^{-4}. These calculations show that for the higher transmissivities, pumping rates on the order of 10,000 ft^3/day will be required. A four inch well with a typical submersible pump may not be able to provide these rates.

Partially penetrating wells in dolomite: The previous tests considered are useful in determining transmissivity and the horizontal component of the hydraulic conductivity. To characterize the vertical connectivity of the water-bearing zones in the dolomite, it is necessary to use different types of well tests. In these tests a vertical

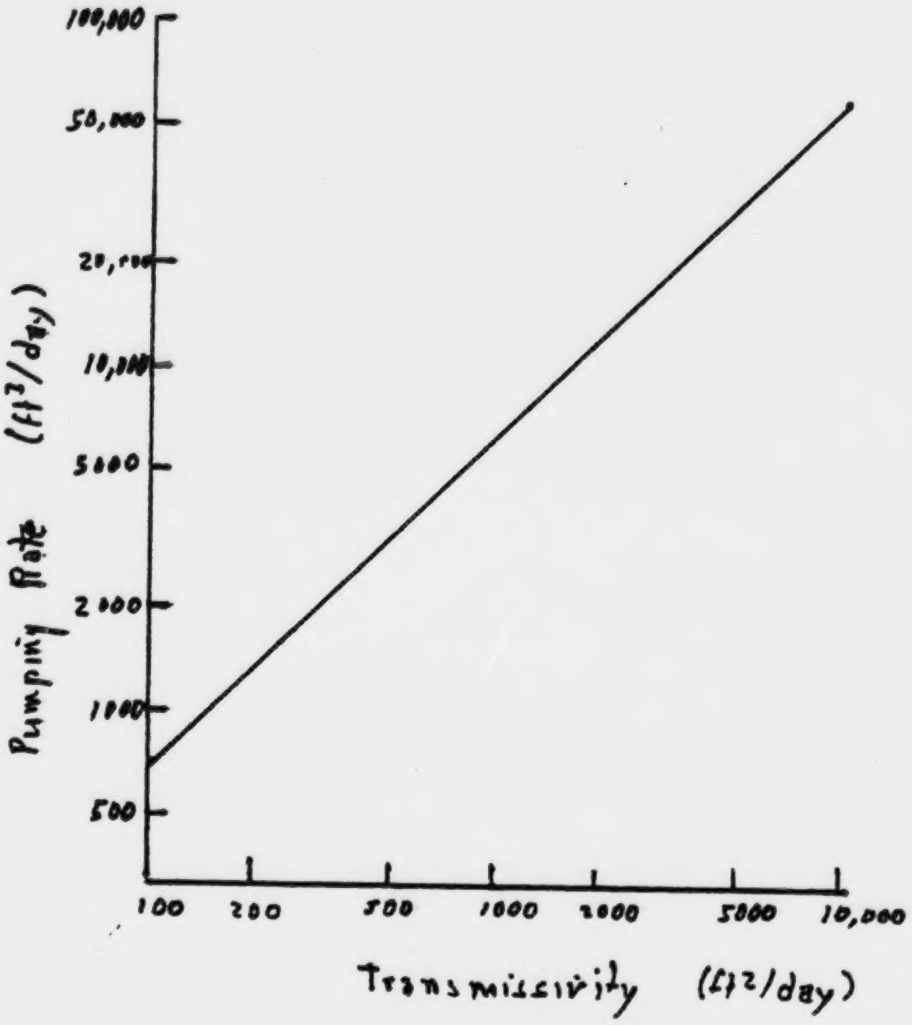

Figure 3. Pumping rate required to attain drawdown of 10 feet in a 4 inch well after one day of pumping as a function of transmissivity (S = .0001).

head gradient is imposed by withdrawing water from one layer of the bedrock. The response in other layers can then provide a basis for estimating the vertical component of hydraulic conductivity. In the Lockport Dolomite it is anticipated that this component will be small in comparison with the horizontal component. Johnston, (1964) documents a great deal of field evidence to support this contention.

An analytical solution that describes the response of water levels in an aquifer to constant discharge from a partially penetrating well is given by Hantush (1964). A copy of the relevant pages from this article is enclosed with this memorandum. The final equation is quite complicated and, in general, requires a computer solution. We have written a program to solve the equation described in section 2, page 353 of the article.

This program can be used to analyze pumping tests conducted on partially penetrating wells if the condition of aquifer homogeneity applies. From Johnston's report (1964), we must assume that homogeneity (relatively uniform properties) is not a good approximation. According to Johnston the top zone of the dolomite is more permeable than the lower zones. In spite of this obvious shortcoming, the analytical solution can provide an idealized model for comparison with field data. Further, it can serve as a point of departure for more realistic simulation of the well tests with numerical models.

The analytical solution provides two generalizations that are useful in designing well tests:

- the largest vertical gradients will occur nearest the well
- at radial distances $r > \frac{3b}{2}\sqrt{K_r/K_z}$, vertical-head gradients will be negligible.

Consequently, if observation wells are drilled, they should be relatively close to the pumping well. To demonstrate this effect more clearly, the results of a few computer runs are shown in figures 4 and 5. The physical problem considered is shown on the inset in figure 4, which shows the drawdowns at the various elevations at the well face after one day of pumping from a thin zone at the base of the well. Figure 5 shows the drawdowns at an observation well 50 feet from the pumping well. As can be readily seen, the rapid changes in drawdown occur near the base of the pumping well. These changes are much less only 50 feet away. Further, the gradients are larger for the higher contrasts in horizontal to vertical permeability. What these results also show, is that it will be important to measure the heads at several elevations in the pumping or observation wells.

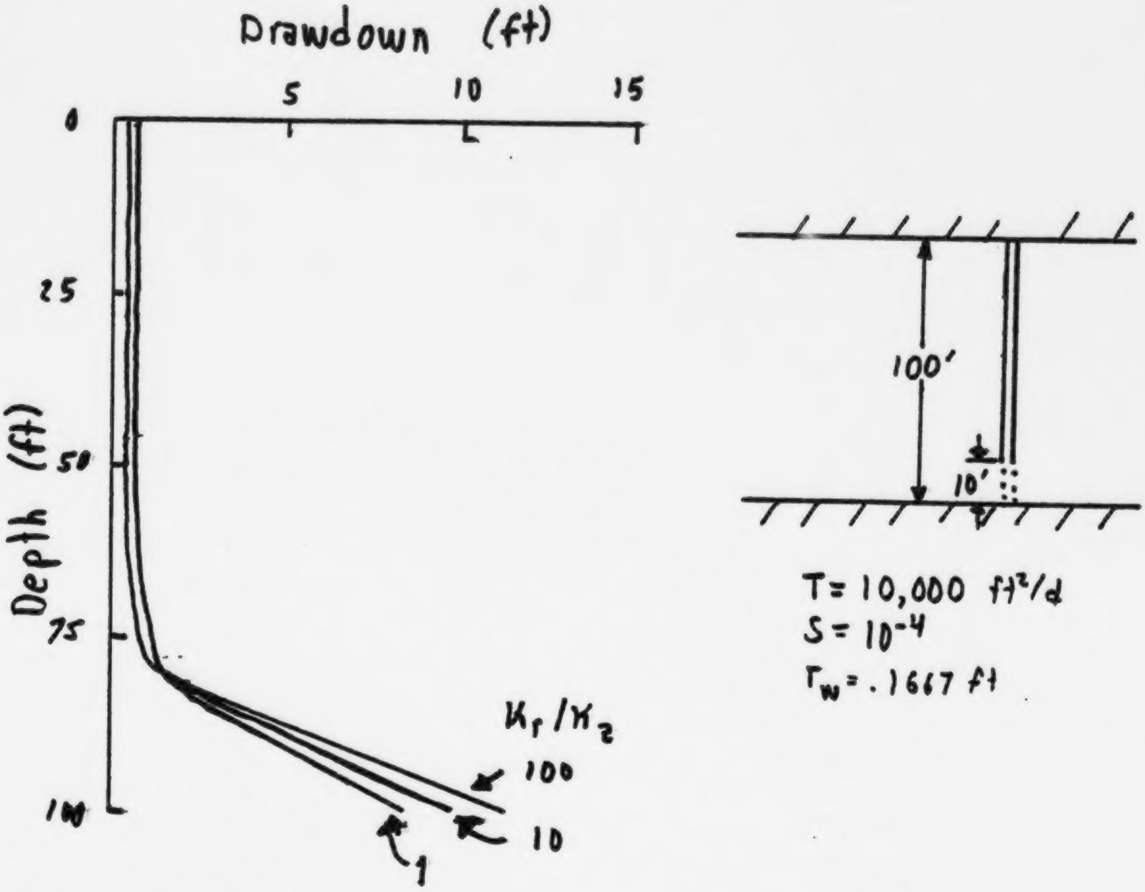

Figure 4. Results of calculations for a partially penetrating well discharging at a constant rate in an anisotropic, homogeneous aquifer -- drawdown at well face. Inset shows positioning of the open interval of the well and other data used in the problem.

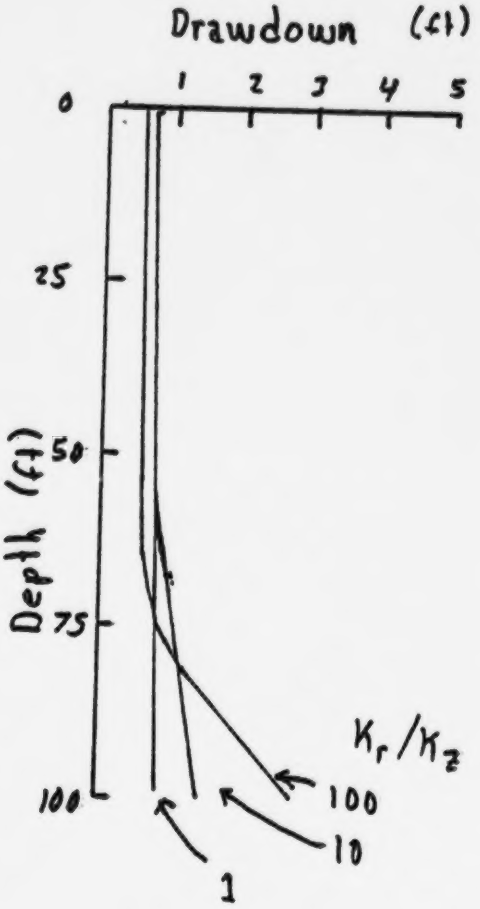

Figure 5. Results of calculations for a partially penetrating well discharging at a constant rate in an anisotropic homogeneous aquifer -- drawdown at a radial distance of 50 feet from pumping well.

Conclusions. Based on our review of the literature and our analysis, we draw the following tentative conclusions:

1) Slug tests in the sandy unit will require measurements for a period on the order of minutes.

2) Slug tests in the clay and till units will require measurements for a period on the order of hours to days.

3) Wells completed in the clay and till may require several days to reequilibrate after construction.

4) Slug tests in the dolomite will generally require short periods of observations, less than a few tens of minutes. For the highly permeable zones, the heads may decline too fast to measure.

5) Pumping tests on fully penetrating bedrock wells may require excessive pumping rates to achieve easily measured drawdowns.

6) Slug tests and fully penetrating well tests will not provide any estimate of the vertical hydraulic conductivity (i.e., the degree of connection between water-bearing layers).

7) Pumping tests on partially penetrating wells can provide estimates of vertical hydraulic conductivity. This requires that heads be measured at several elevations in the pumping or observation wells.

8) The top zones of the dolomite are more permeable than the lower zones.

9) Numerical models will be necessary to analyze the pumping test data for partially penetrating wells, but an analytical solution for homogeneous conditions can provide an initial analysis.

10) For a partially penetrating well test, the most rapid vertical changes in head will occur near the zone of pumping, while at distances much greater than a few hundred feet, vertical-head gradients caused by the pumping may not be large. Therefore, if observation wells are drilled, they should be relatively close to the pumping well.

11) In order to attain useful information from the well tests, it is important that they be properly designed and carefully conducted. In designing the tests it is necessary to consider the types of geological units to be encountered, the information to be gained, and the capabilities of the equipment to be used in the tests.

12) The credibility of the modeling analysis and predictions that are made for the Love Canal site can be no higher than the quality and completeness of the field data permit.

Recommendations. We recommend the following:

1) Written protocols should be prepared for each type of well test before it is used.

2) Well test protocols should recognize that actual field conditions will dictate appropriate timing of water-level observations.

3) For the slug tests, the calculations provided in this memorandum can provide a guide to anticipated observation periods.

4) Water-level measurements should be taken at logarithmic intervals for all of the tests considered.

5) Because well tests in the dolomite are important in determining contamination potentials of a ground-water resource, it is necessary that these tests be conducted to maximize information obtained. Therefore, rather than drilling six bedrock wells to the Rochester Shale, we suggest drilling those six wells only through the top 20 feet of the Lockport. Then, based on the slug tests conducted on these wells (and contamination), select three sites for detailed testing. At each of the three sites, an additional well should be drilled to the base of the Lockport Dolomite. The new well should be located about 20 feet from the original well. A combination of slug tests and pumping tests using packers should then be performed on each well pair.

6) The majority of these bedrock wells should be drilled to the west of the landfill in order to optimize success of determining any contamination of the Lockport. Care should be exercised to prevent contamination of the Lockport from above during drilling.

Additional Data Needs. Additional data needs include:

1) The USGS has 13 wells on record in Niagara County -- can water levels in these wells be measured? These would be helpful in constructing a potentiometric surface for the Lockport Dolomite.

2) How much water is processed weekly at the treatment facility?

3) When were the drains installed and operational?

References

Cooper, H.H., J.D. Bredehoeft, and I.S. Papadopulos, 1967, Response of a finite-diameter well to an instantaneous charge of water, Water Resources Research, pp. 263-269.

Ferris, J.G., and D.B. Knowles, 1954, The slug test for estimating transsibility, U.S. Geol. Survey Ground Water Note 26.

Hantush, M.S., 1964, Hydraulics of wells: in Advances in Hydroscience, V.T. Chow, ed., New York, Academic Press, p. 281-432.

APPENDIX C. VARIABLE RATE DISCHARGE TEST ANALYSIS

This appendix includes the results of the analysis of the declining discharge test conducted on well 72 at the Love Canal site on 13-14 October 1980. The analysis involves matching the observed data to the theoretical solution for variable rate discharge tests. The procedure for matching the data is based on least squares minimization. Both the theoretical model and computational approach are discussed in Section 4.3.1 of this report.

The available data is matched in three different sets:

(1) Case A - All the data are matched simultaneously with one set of hydrologic parameters (T and S). This leads to a field average value of these parameters but comparison between observed and calculated data in individual wells is only fair.

(2) Case B - Data on individual observation wells is matched independently of other wells. This leads to a different value of T and S for each well. In this case, good agreement is achieved between observed and calculated data.

(3) In the third category recovery data is matched. After the pumping stopped, recovery was measured in three wells. Comparisons of observed data for these wells are very good.

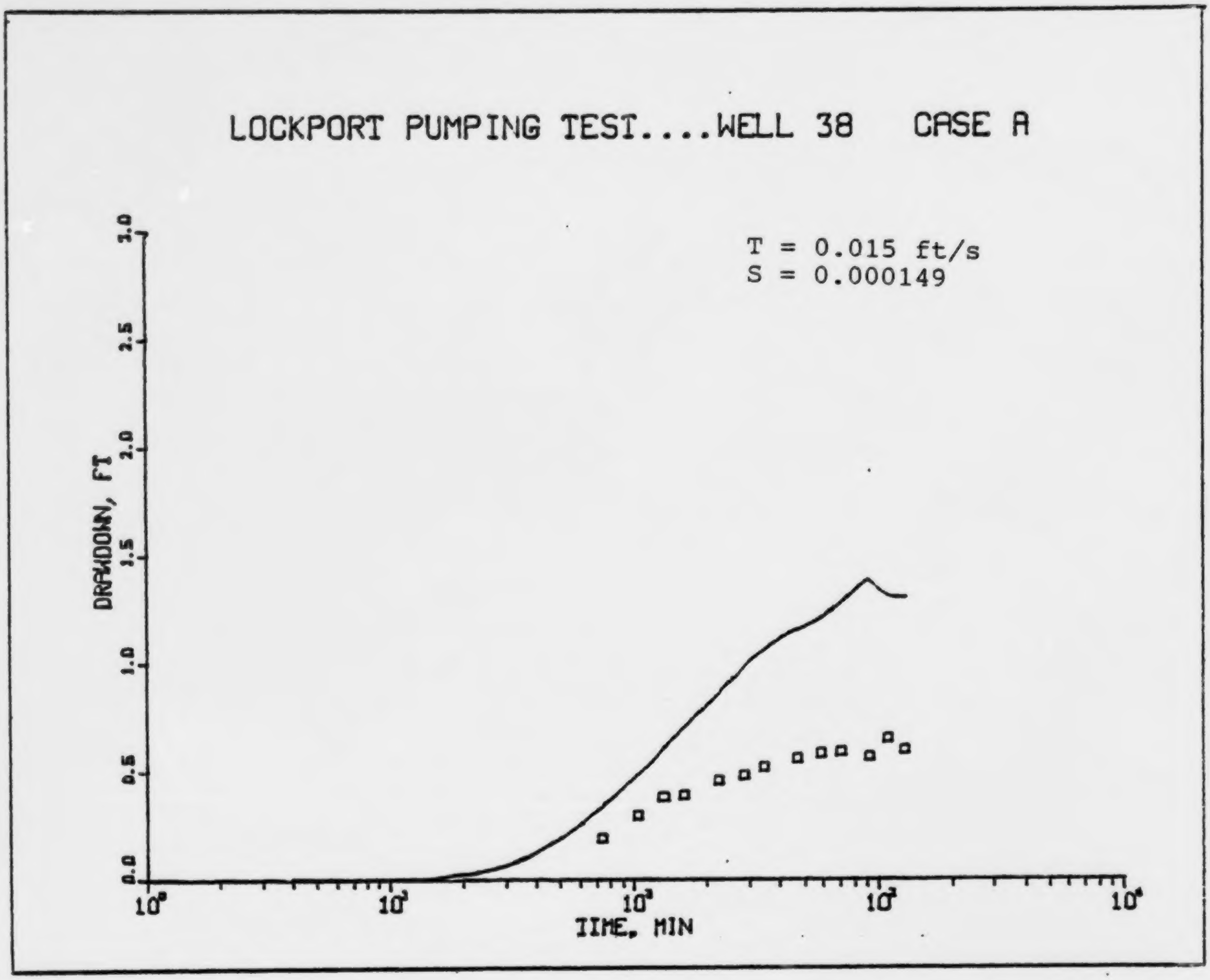

Figure C.1 Plot of Well 38 of observed drawdowns and theoretical drawdowns using T and S fitted to data from all wells.

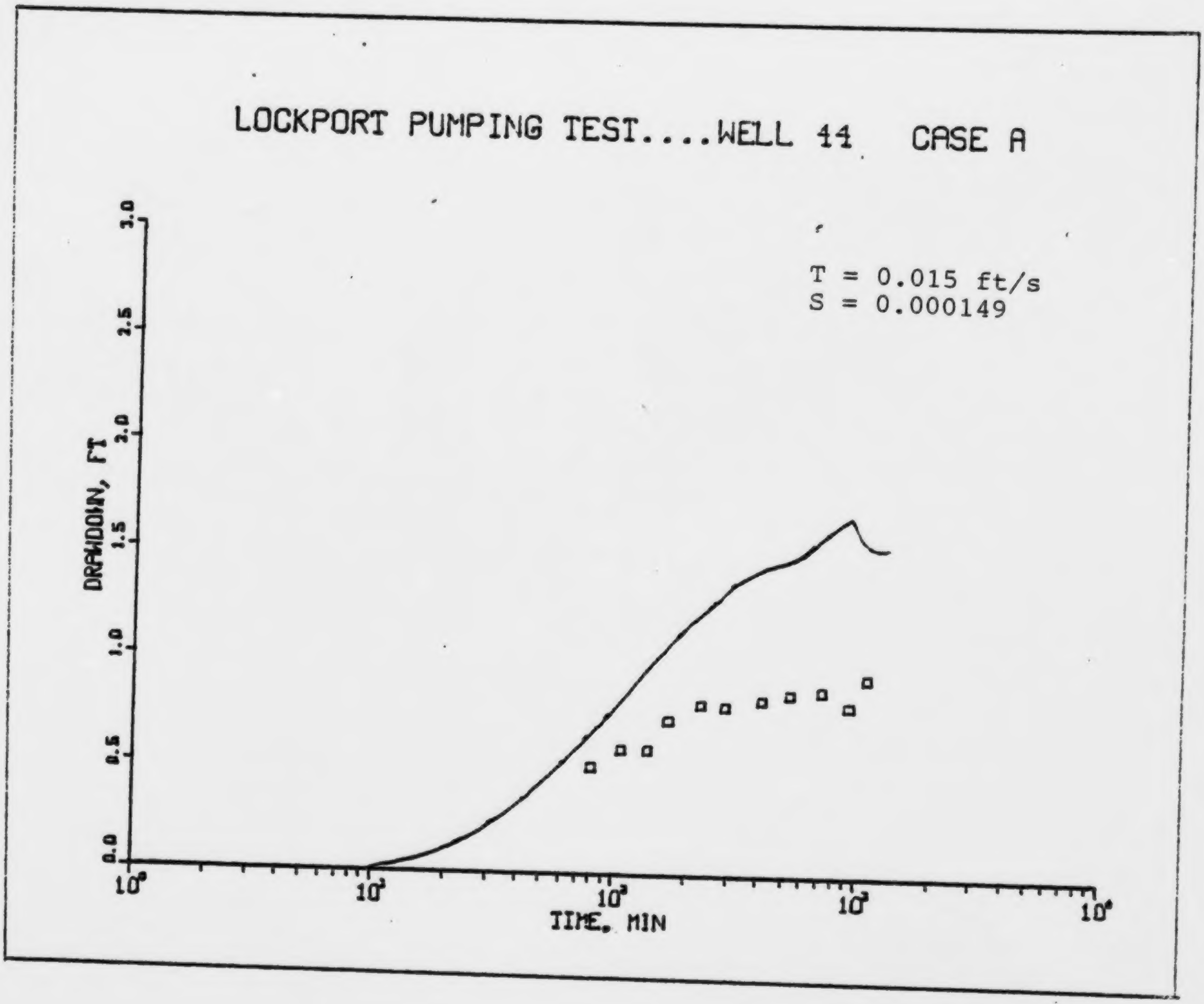

Figure C.2 Plot of Well 44 of observed drawdowns and theoretical drawdowns using T and S fitted to data from all wells.

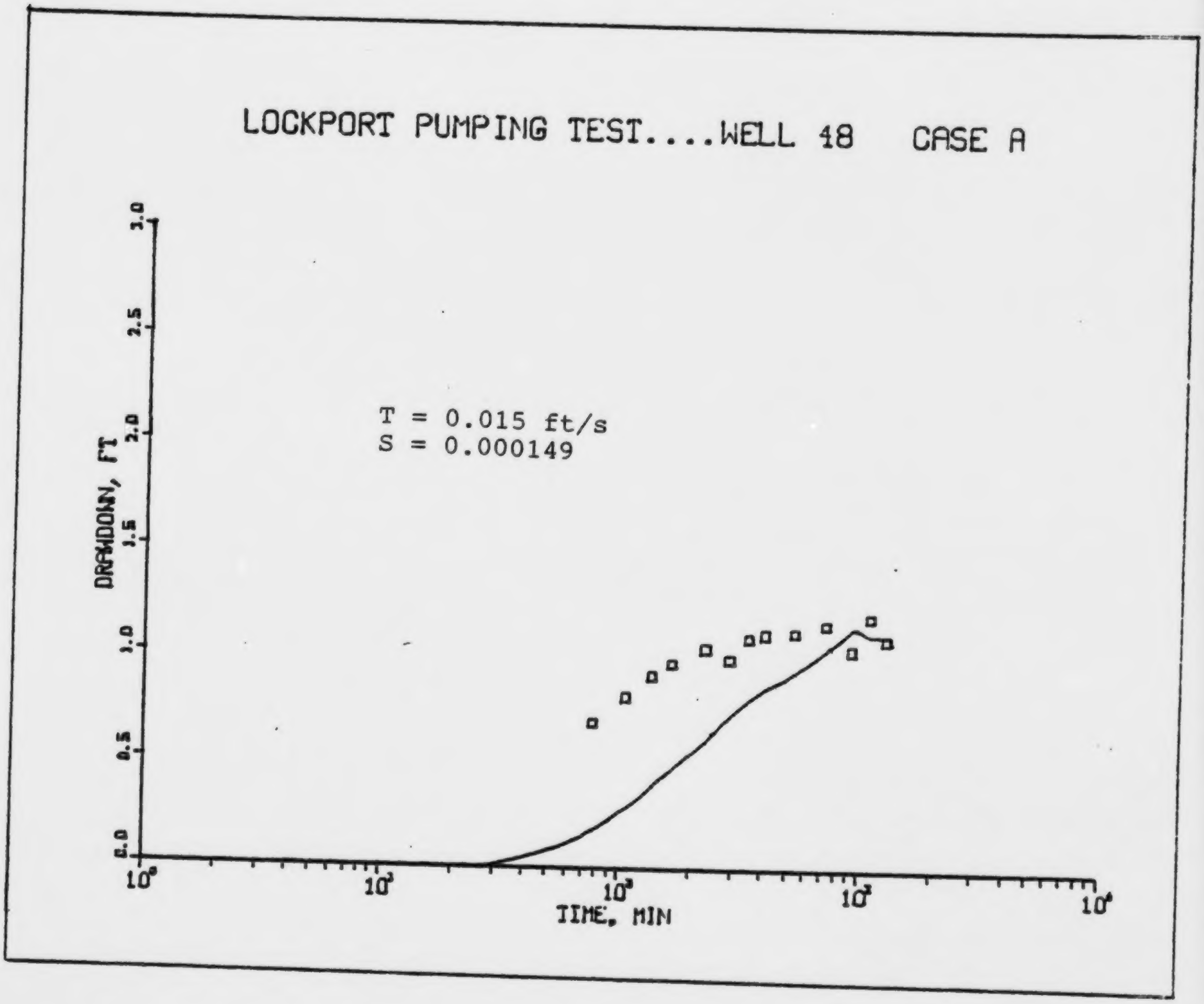

Figure C.3 Plot of Well 48 of observed drawdowns and theoretical drawdowns using T and S fitted to data from all wells.

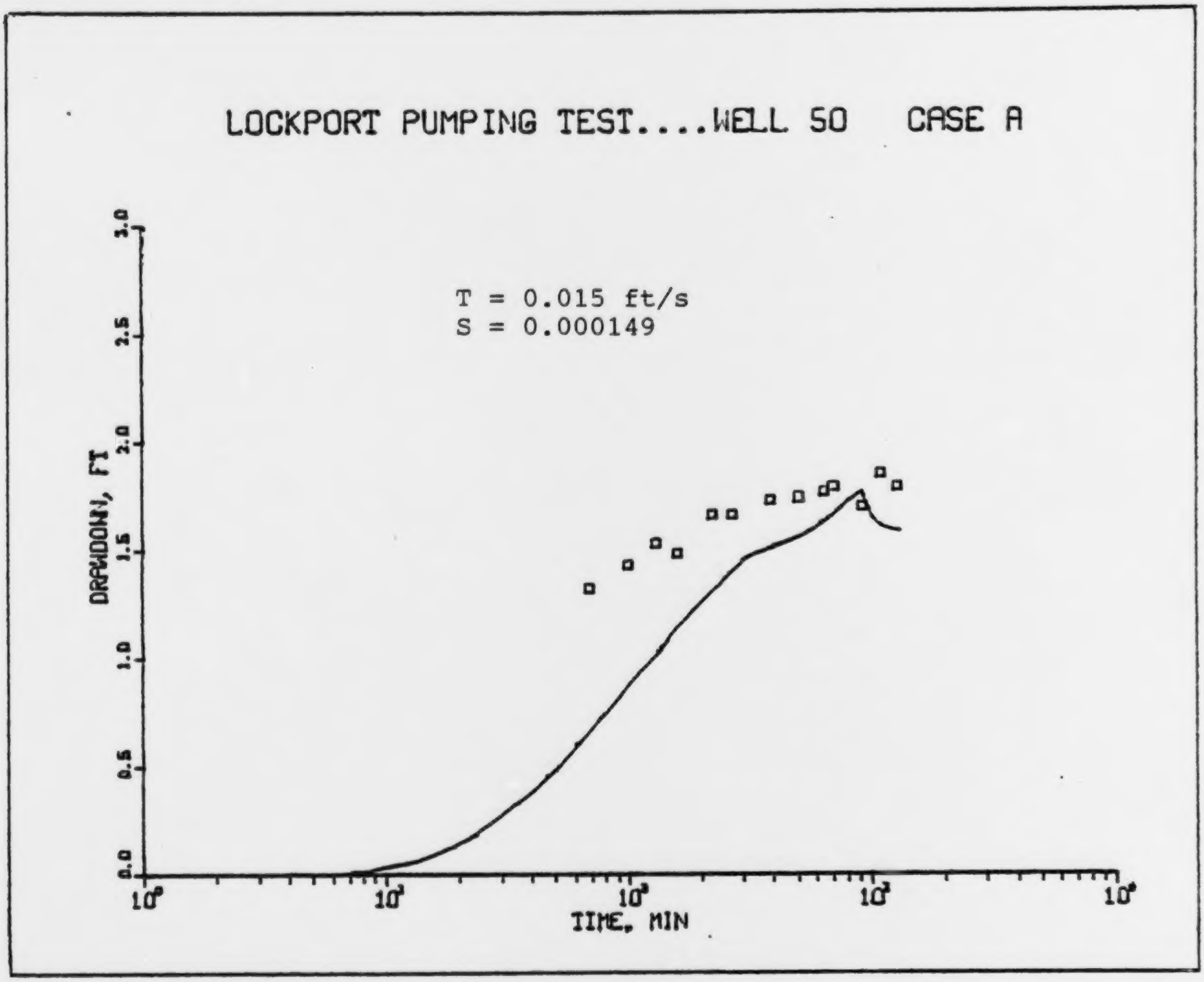

Figure C.4 Plot of Well 50 of observed drawdowns and theoretical drawdowns using T and S fitted to data from all wells.

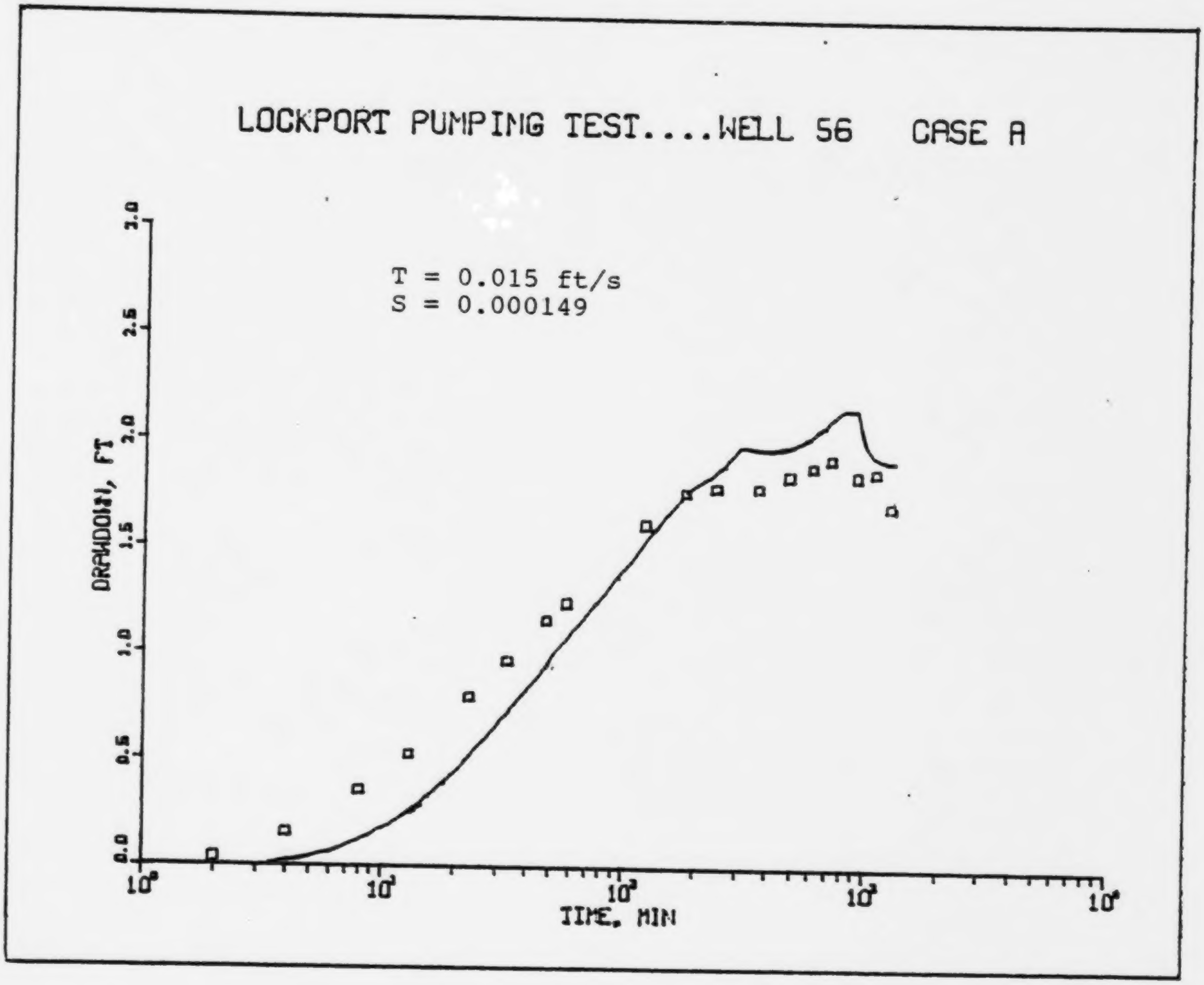

Figure C.5 Plot of Well 56 of observed drawdowns and theoretical drawdowns using T and S fitted to data from all wells.

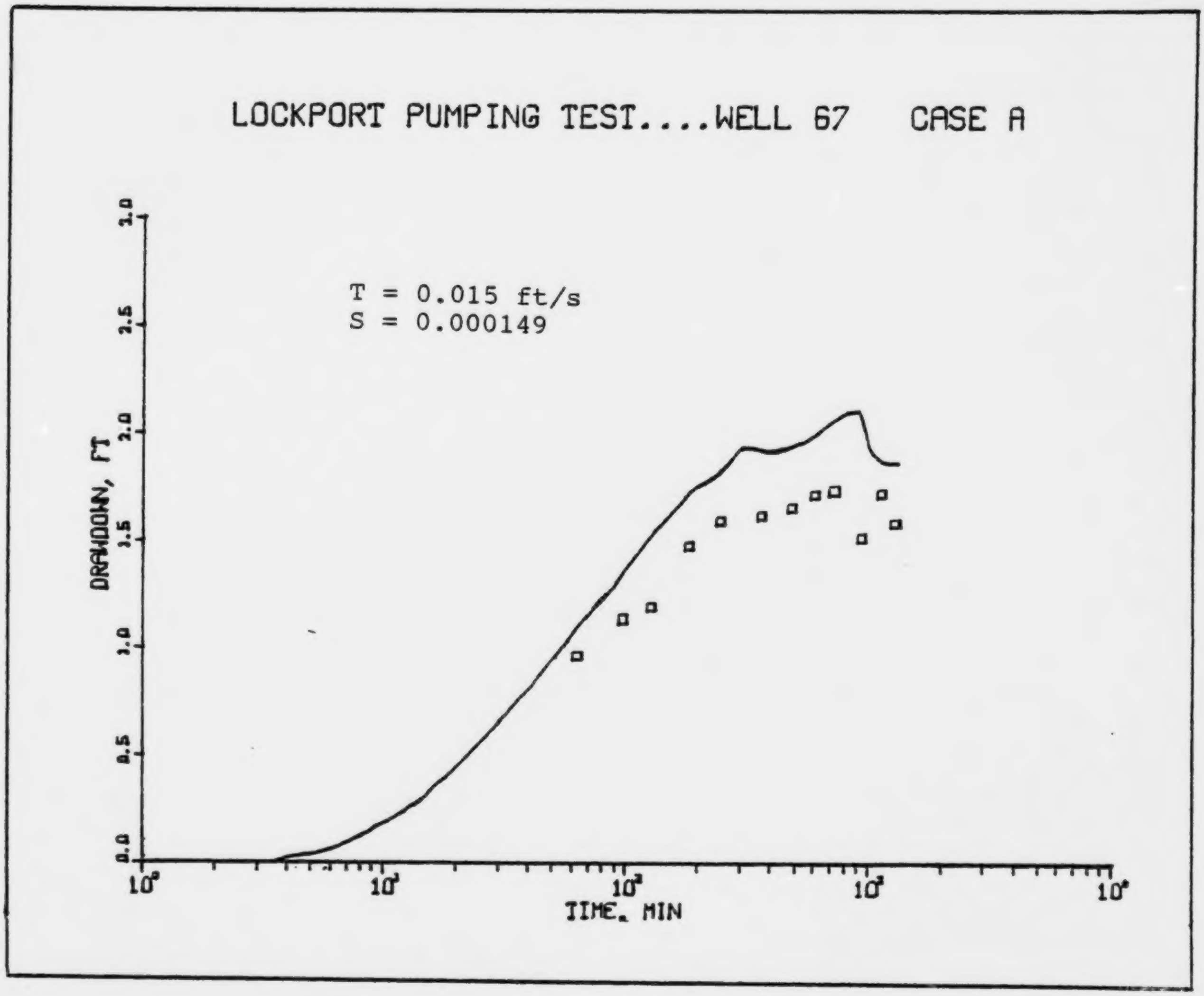

Figure C.6 Plot of Well 67 of observed drawdowns and theoretical drawdowns using T and S fitted to data from all wells.

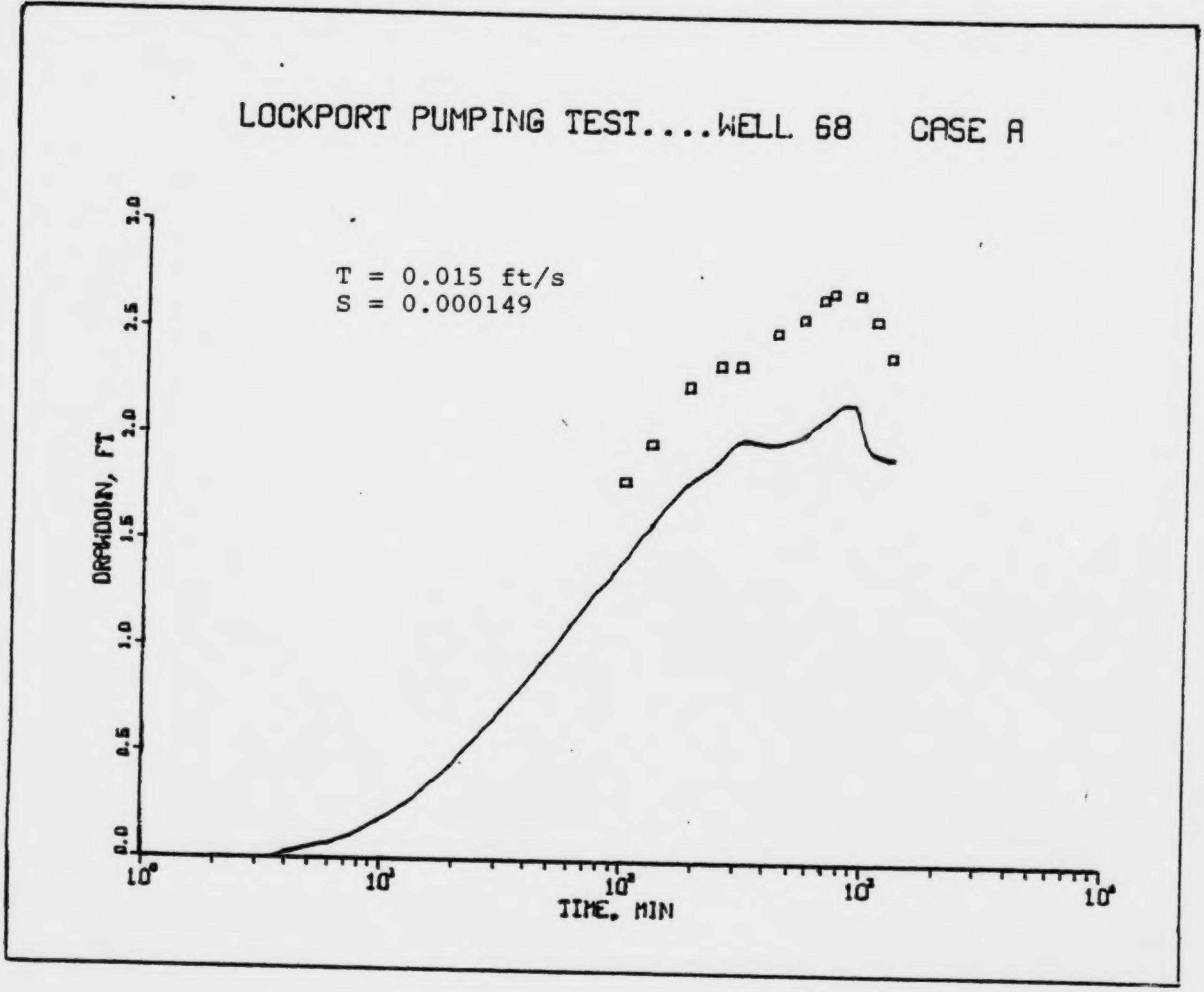

Figure C.7 Plot of Well 68 of observed drawdowns and theoretical drawdowns using T and S fitted to data from all wells.

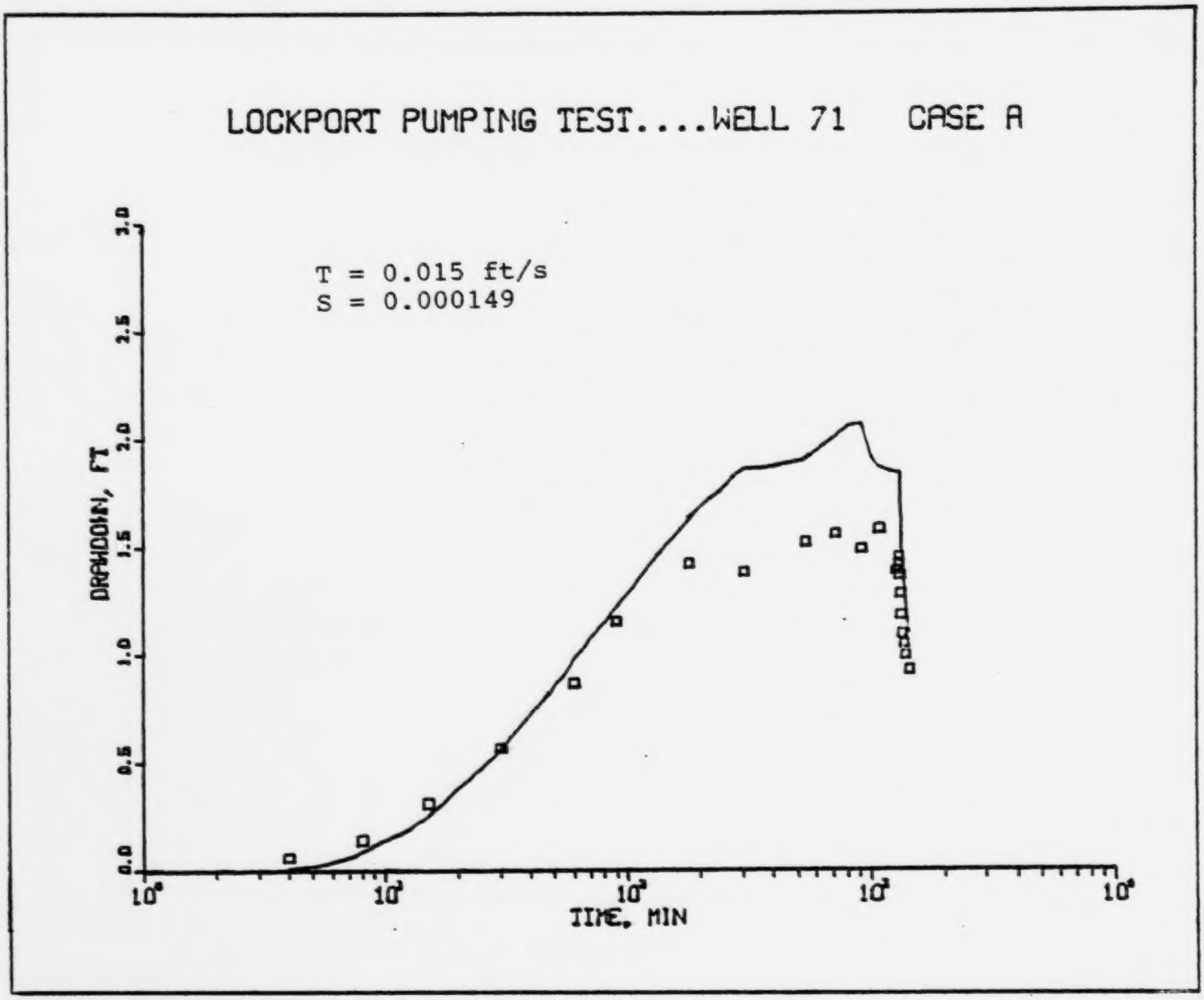

Figure C.8 Plot of Well 71 of observed drawdowns and theoretical drawdowns using T and S fitted to data from all wells.

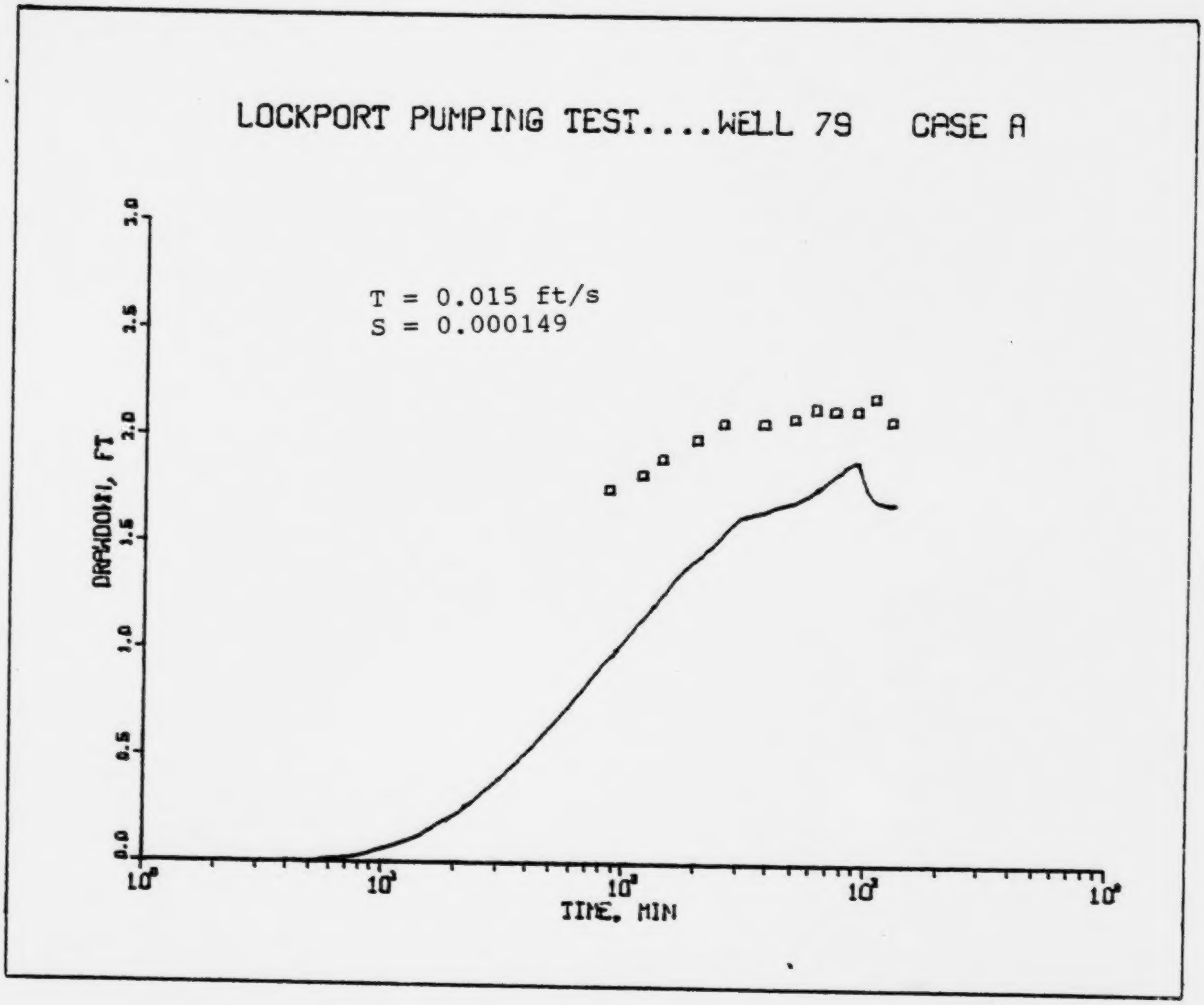

Figure C.9 Plot of Well 79 of observed drawdowns and theoretical drawdowns using T and S fitted to data from all wells.

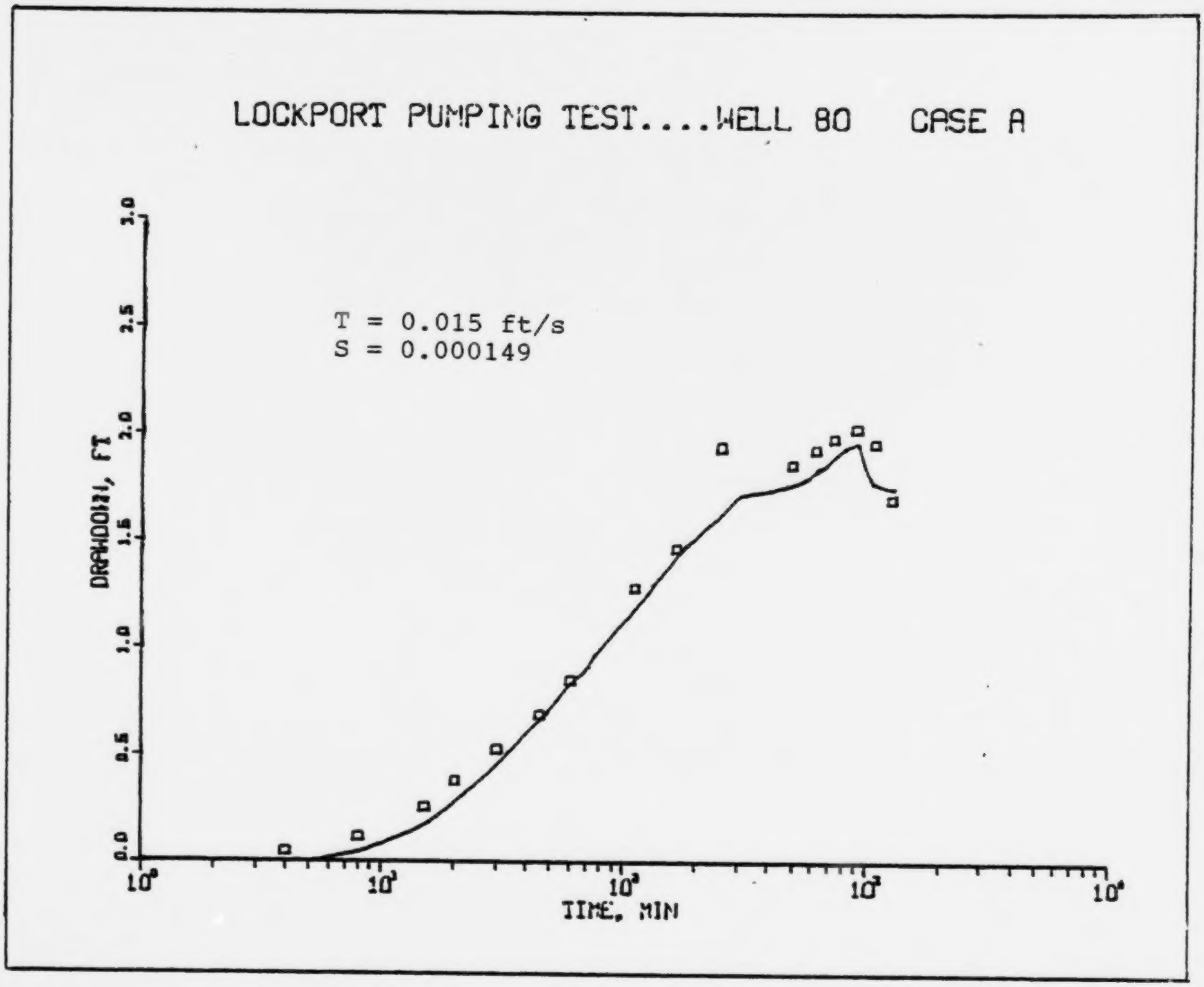

Figure C.10 Plot of Well 80 of observed drawdowns and theoretical drawdowns using T and S fitted to data from all wells.

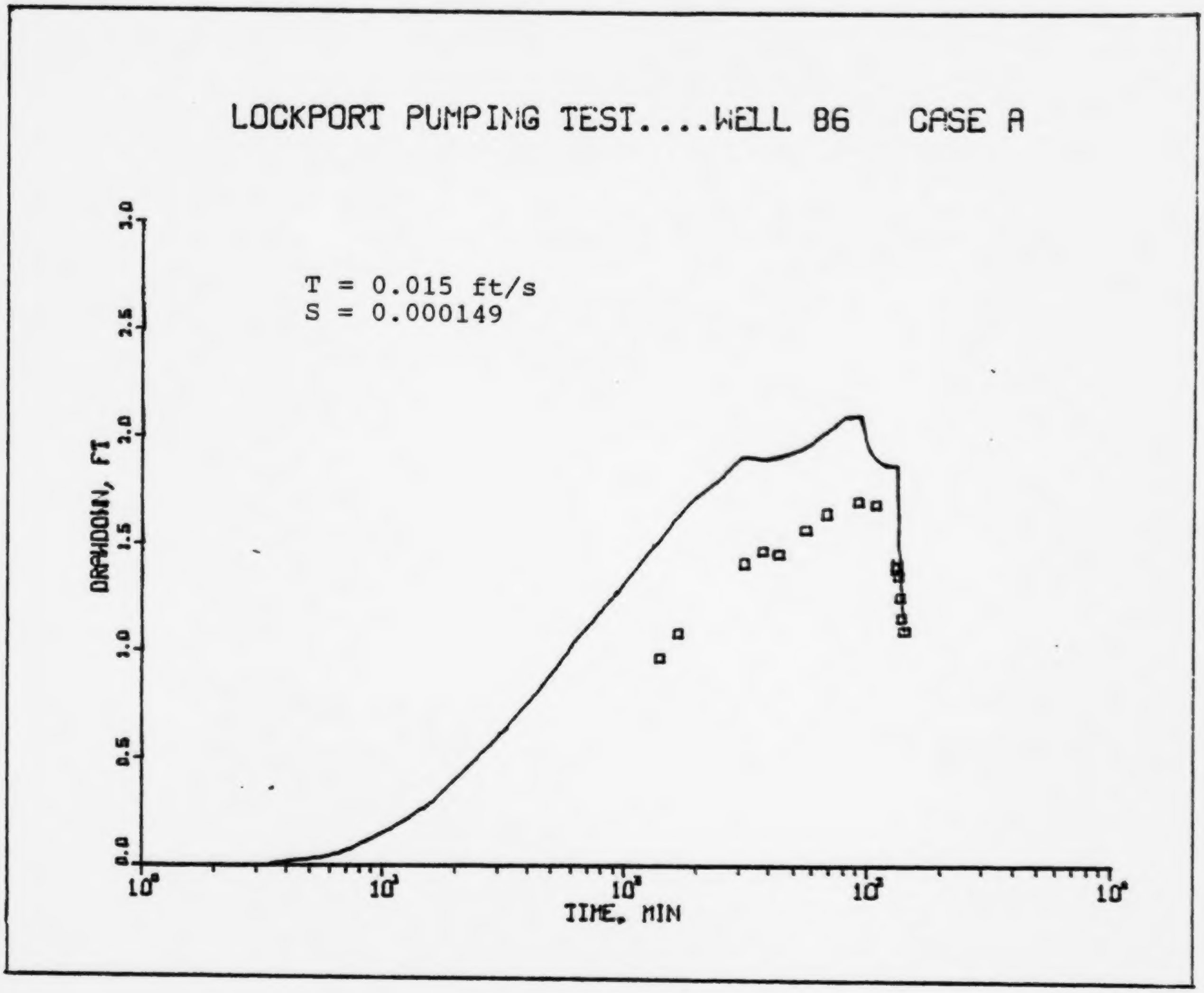

Figure C.11 Plot of Well 86 of observed drawdowns and theoretical drawdowns using T and S fitted to data from all wells.

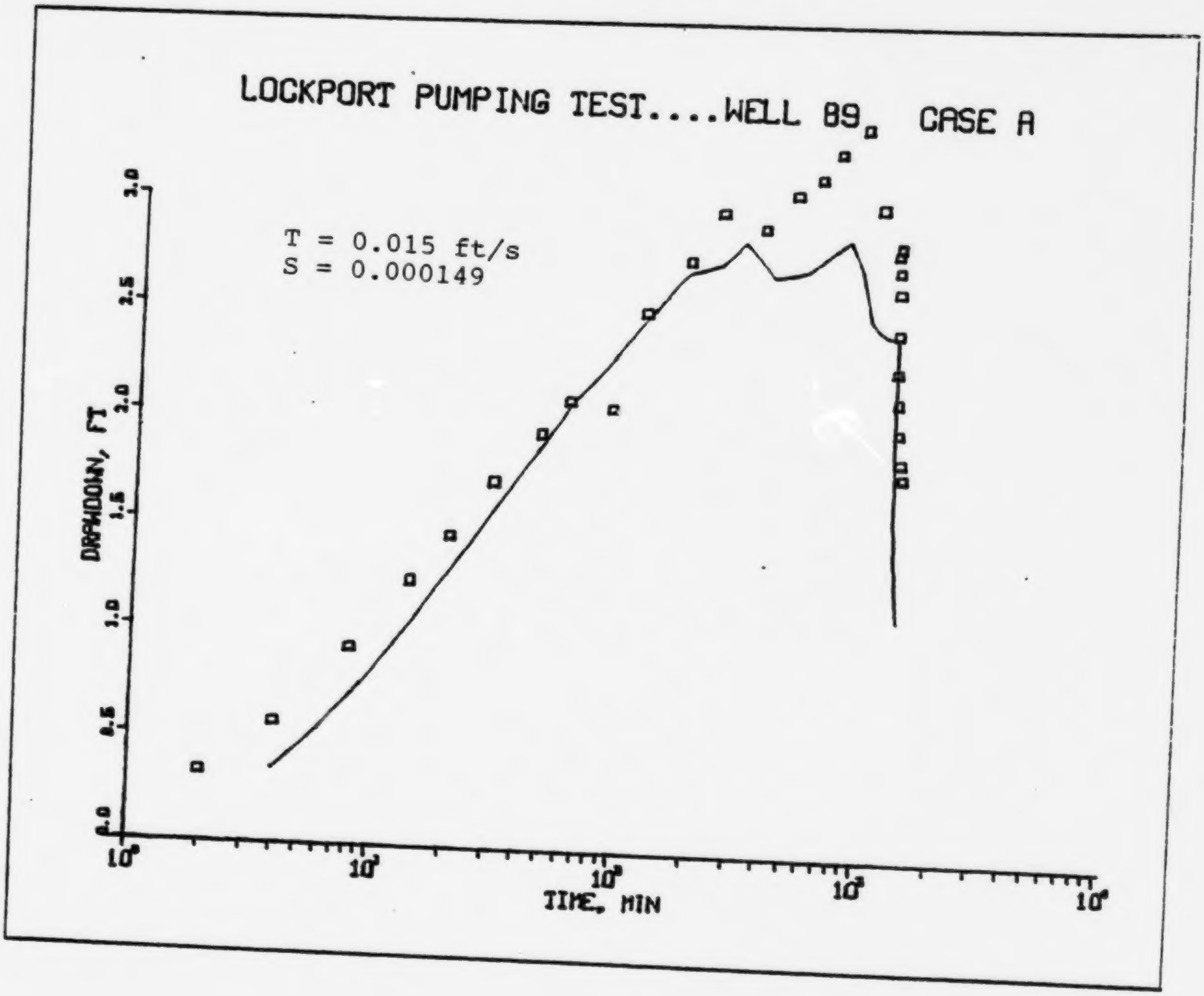

Figure C.12 Plot of Well 89 of observed drawdowns and theoretical drawdowns using T and S fitted to data from all wells.

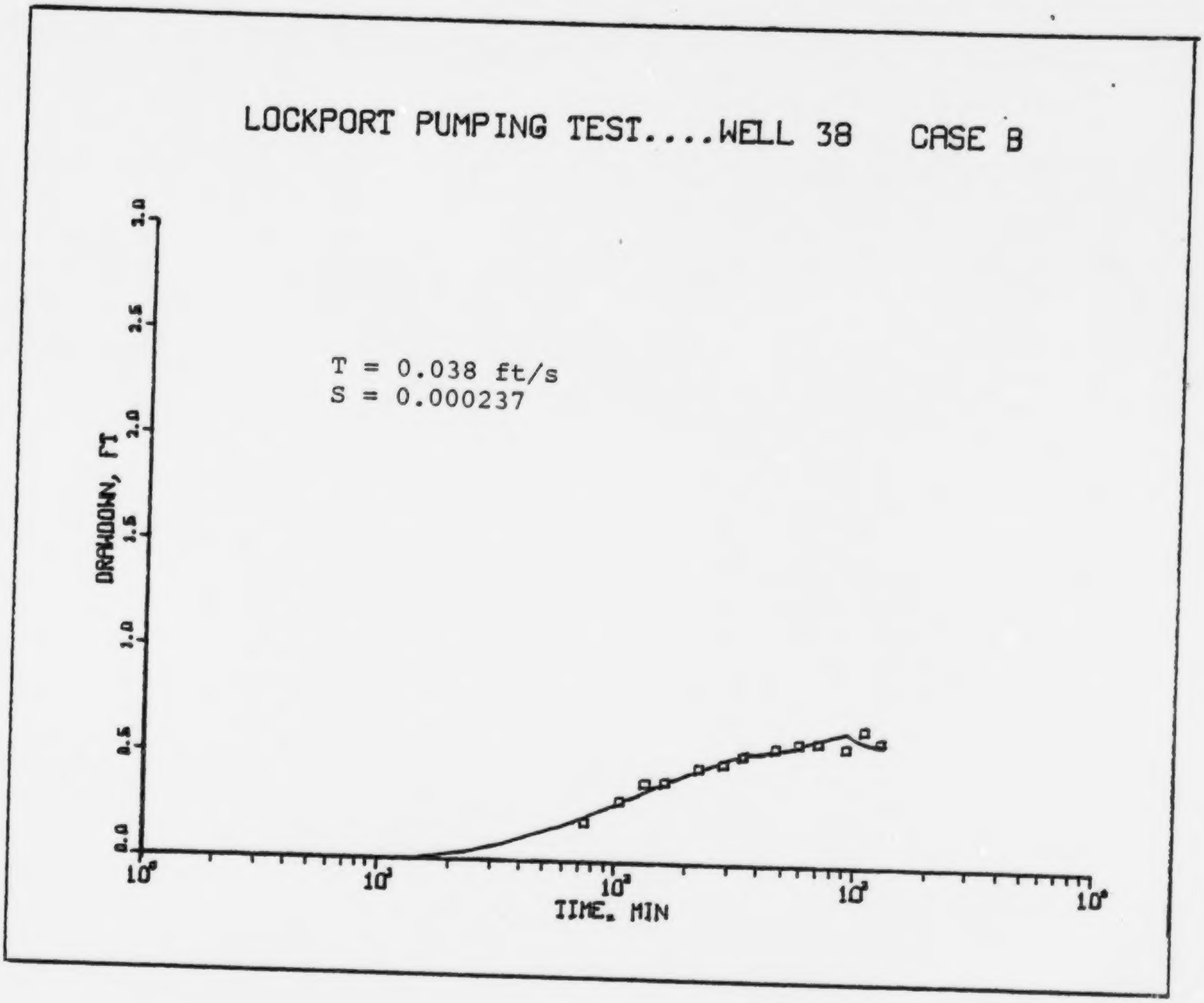

Figure C.13 Plot of Well 38 of observed drawdowns and theoretical drawdowns using T and S fitted to data from this well only.

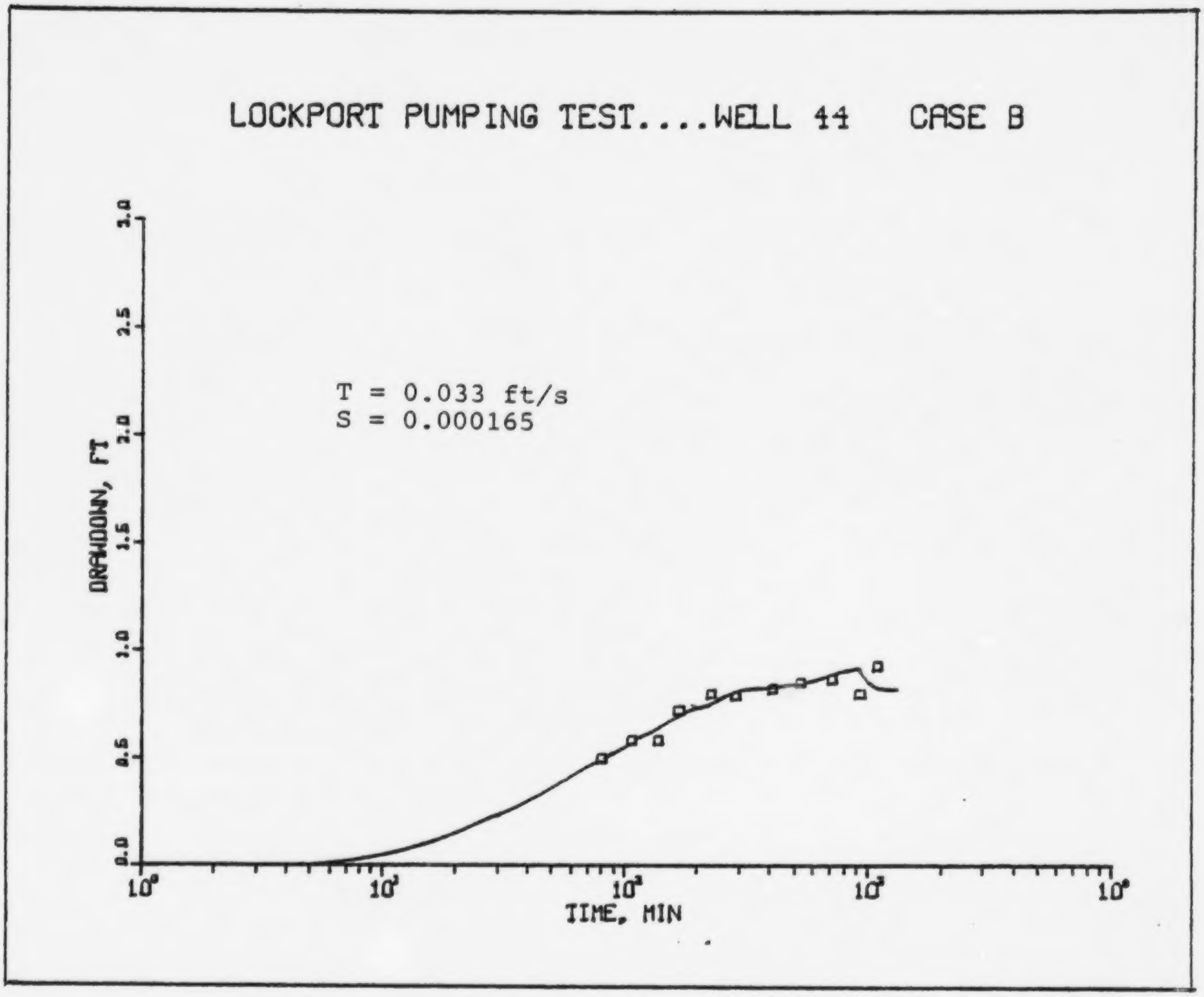

Figure C.14 Plot of Well 44 of observed drawdowns and theoretical drawdowns using T and S fitted to data from this well only.

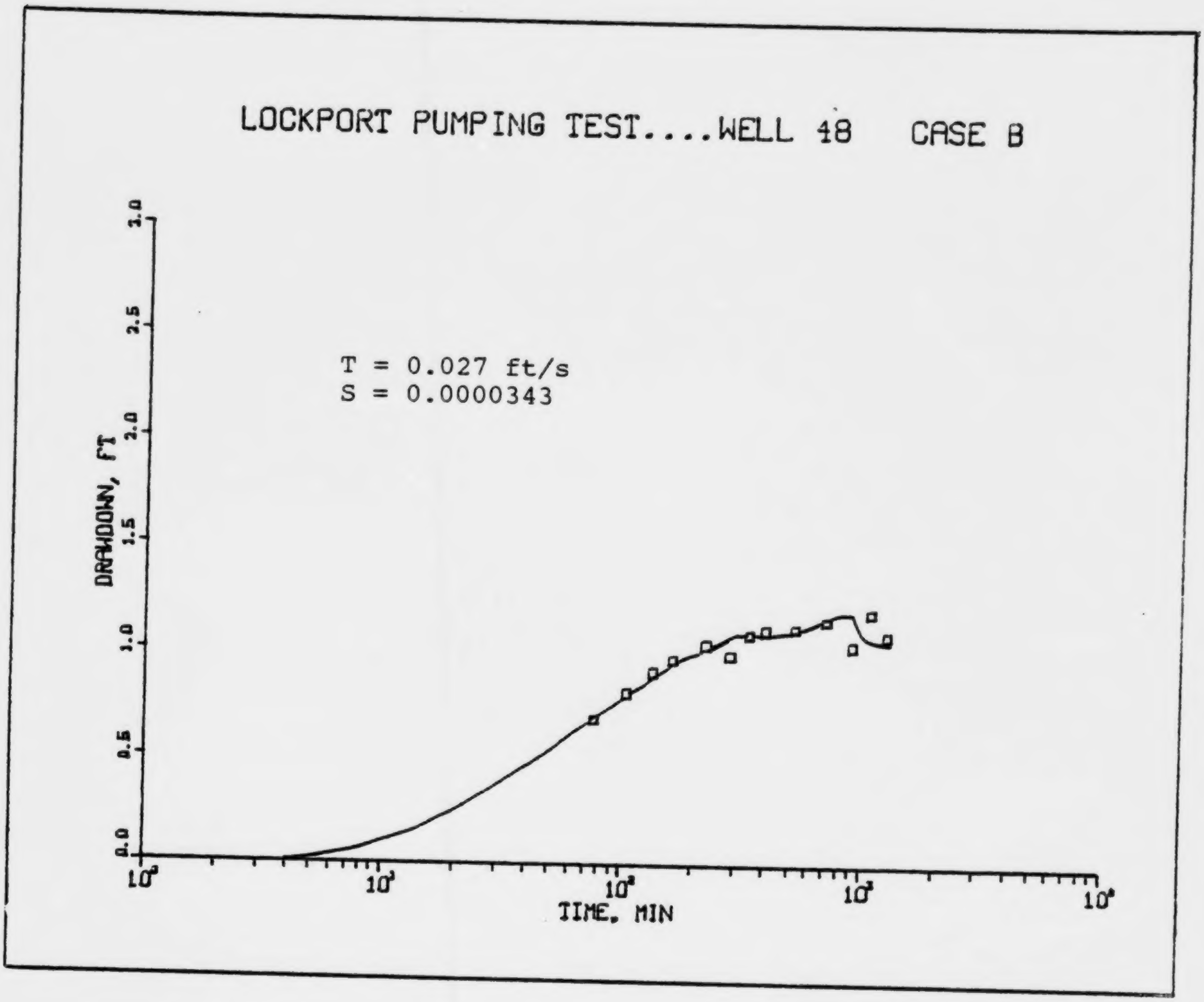

Figure C.15 Plot of Well 48 of observed drawdowns and theoretical drawdowns using T and S fitted to data from this well only.

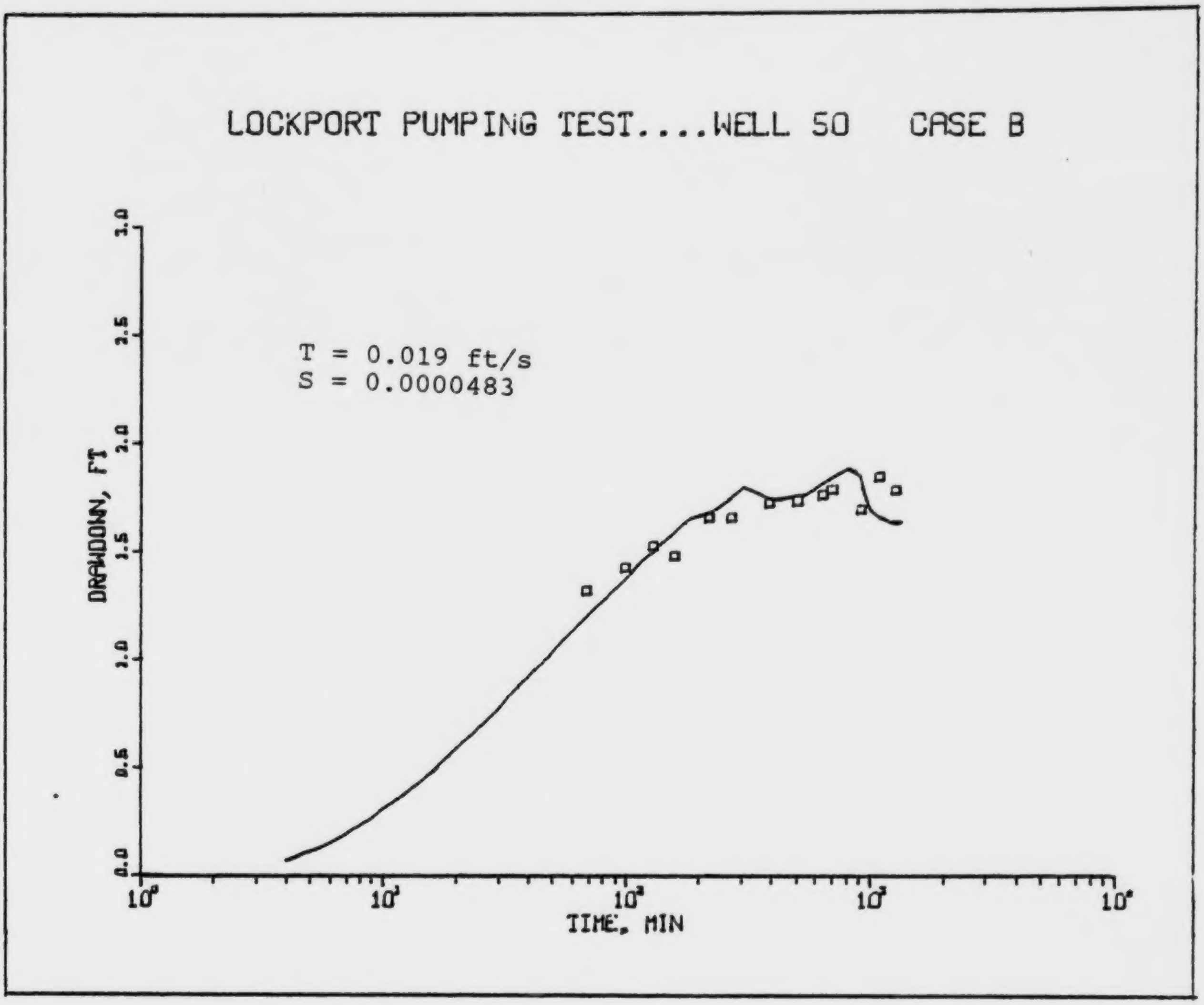

Figure C.16 Plot of Well 50 of observed drawdowns and theoretical drawdowns using T and S fitted to data from this well only.

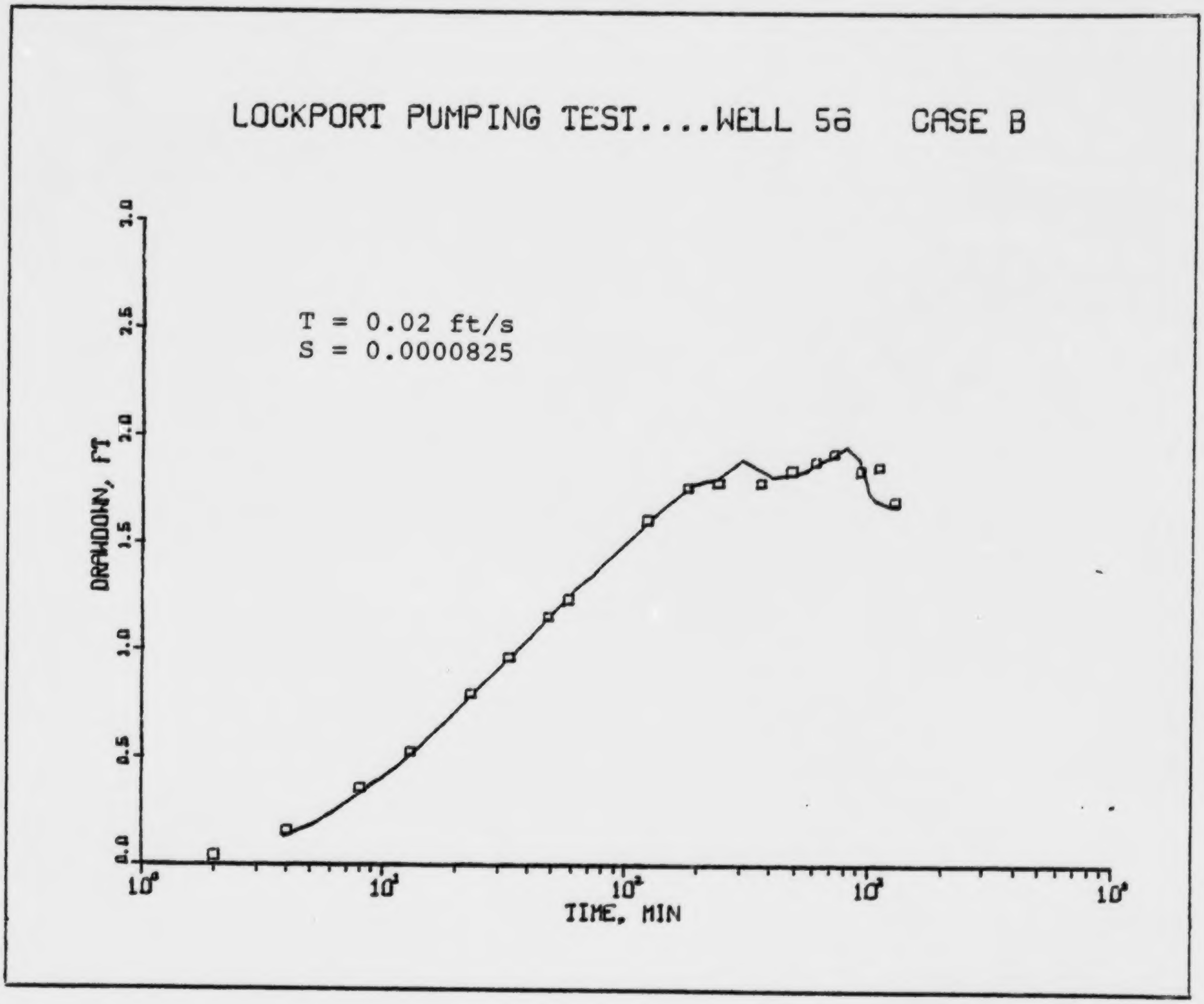

Figure C.17 Plot of Well 56 of observed drawdowns and theoretical drawdowns using T and S fitted to data from this well only.

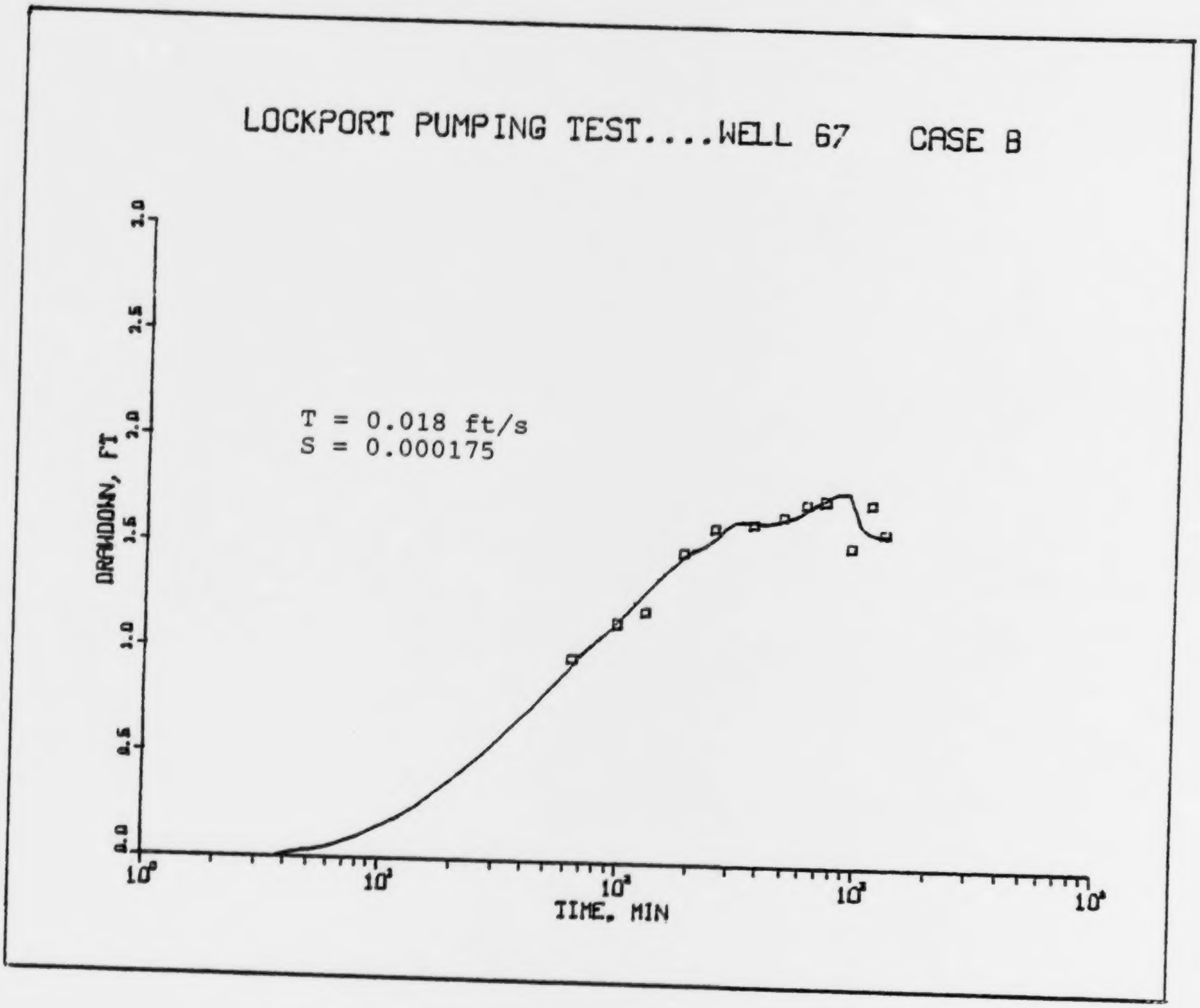

Figure C.18 Plot of Well 67 of observed drawdowns and theoretical drawdowns using T and S fitted to data from this well only.

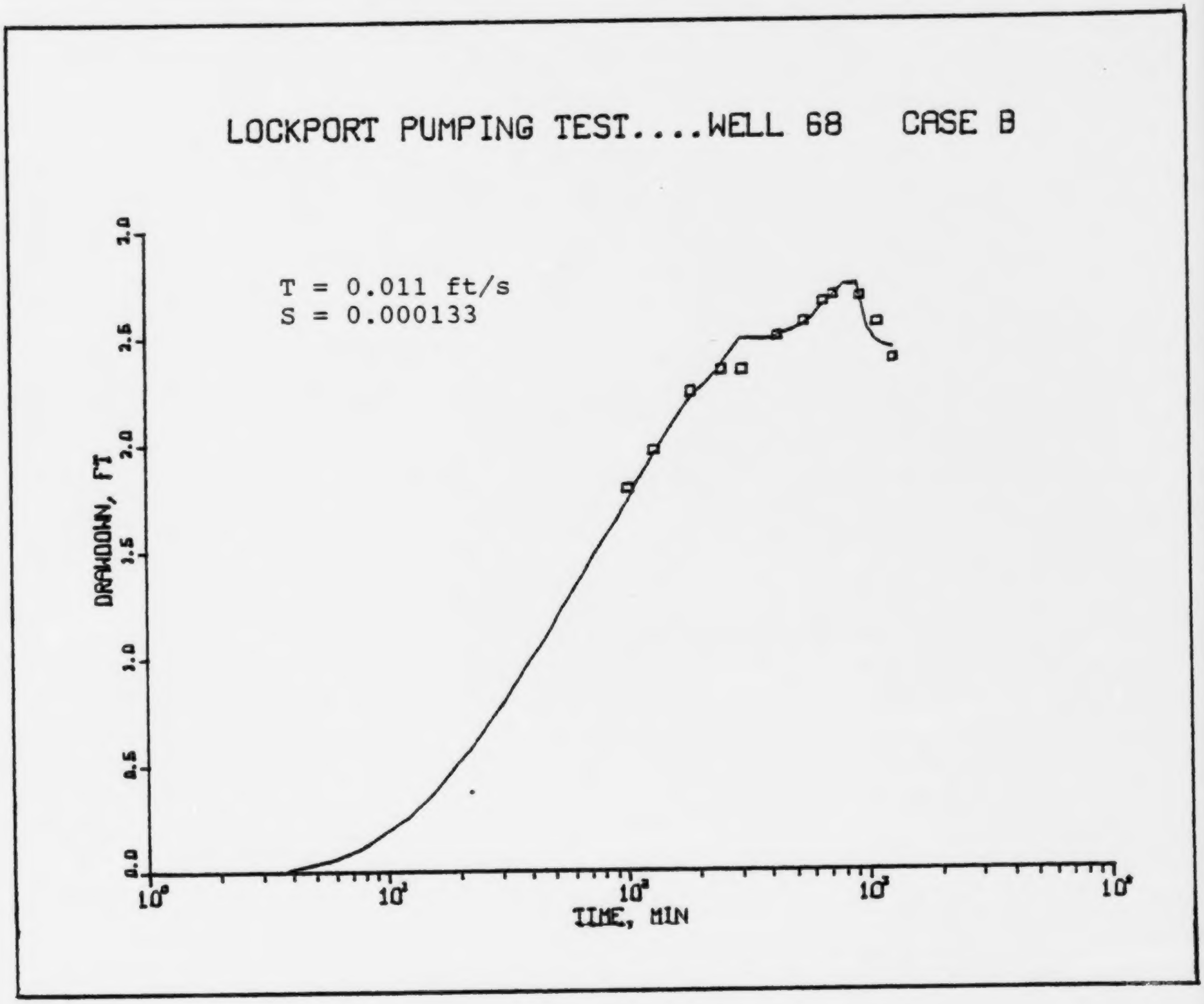

Figure C.19 Plot of Well 68 of observed drawdowns and theoretical drawdowns using T and S fitted to data from this well only.

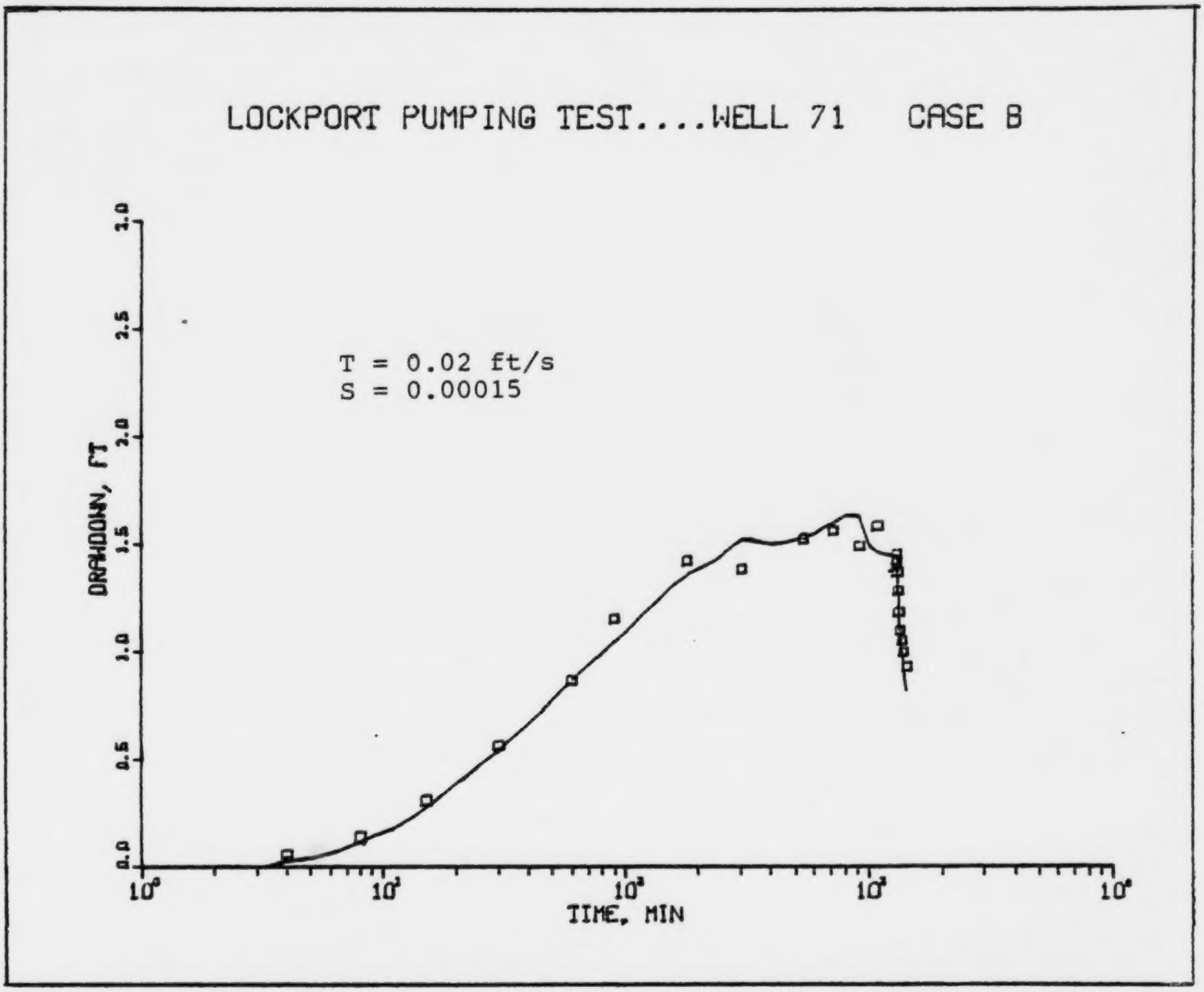

Figure C.20 Plot of Well 71 of observed drawdowns and theoretical drawdowns using T and S fitted to data from this well only.

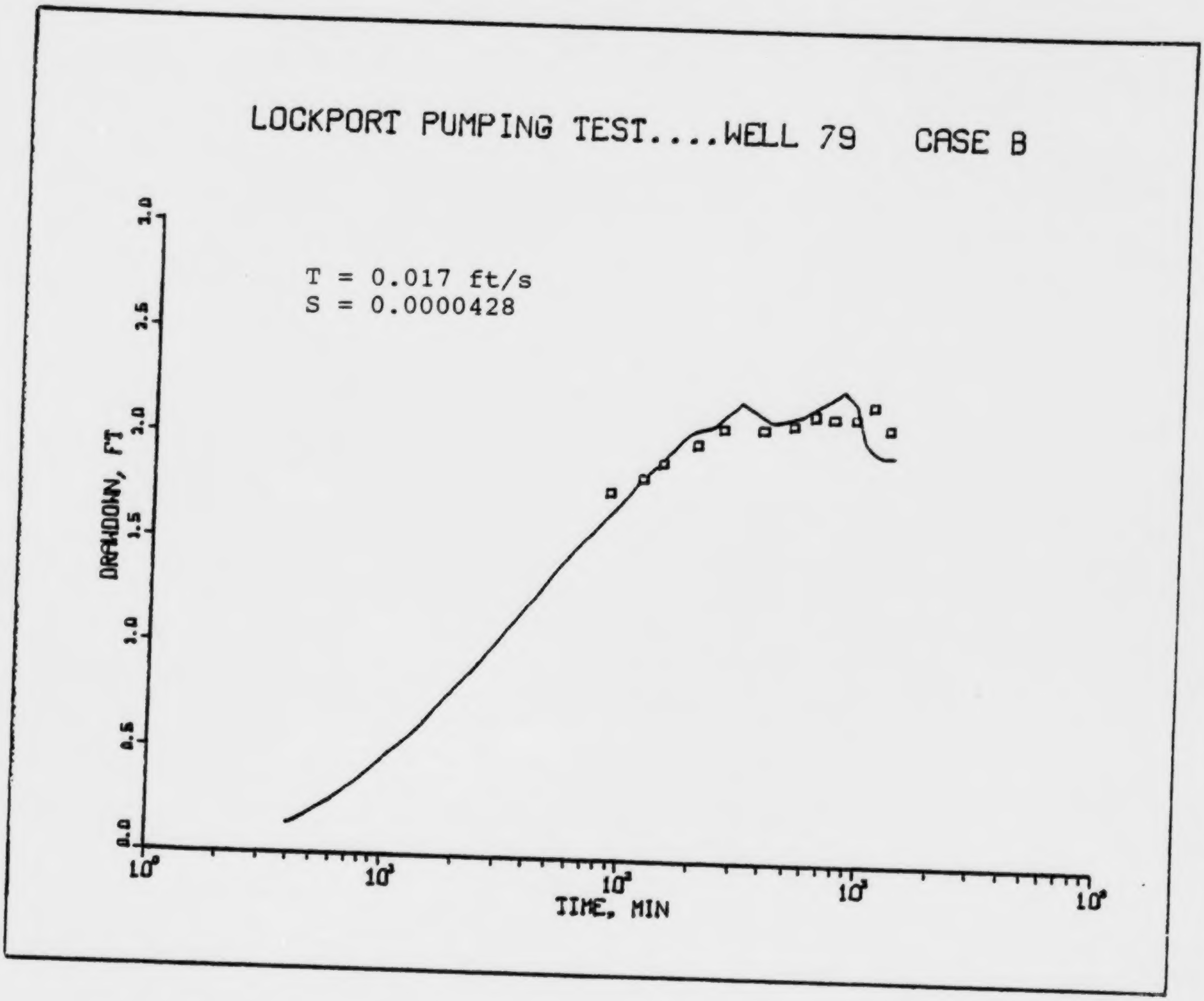

Figure C.21 Plot of Well 79 of observed drawdowns and theoretical drawdowns using T and S fitted to data from this well only.

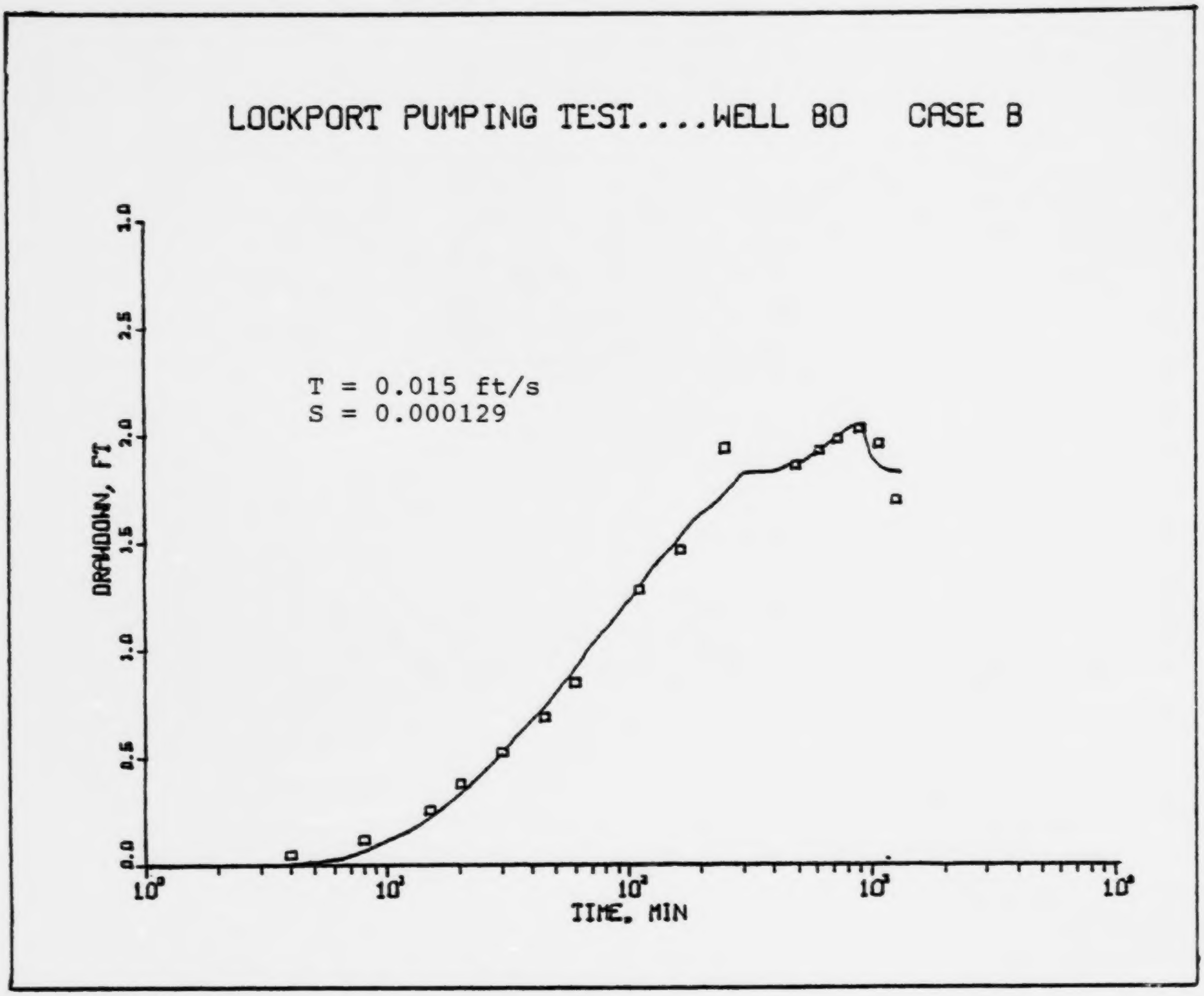

Figure C.22 Plot of Well 80 of observed drawdowns and theoretical drawdowns using T and S fitted to data from this well only.

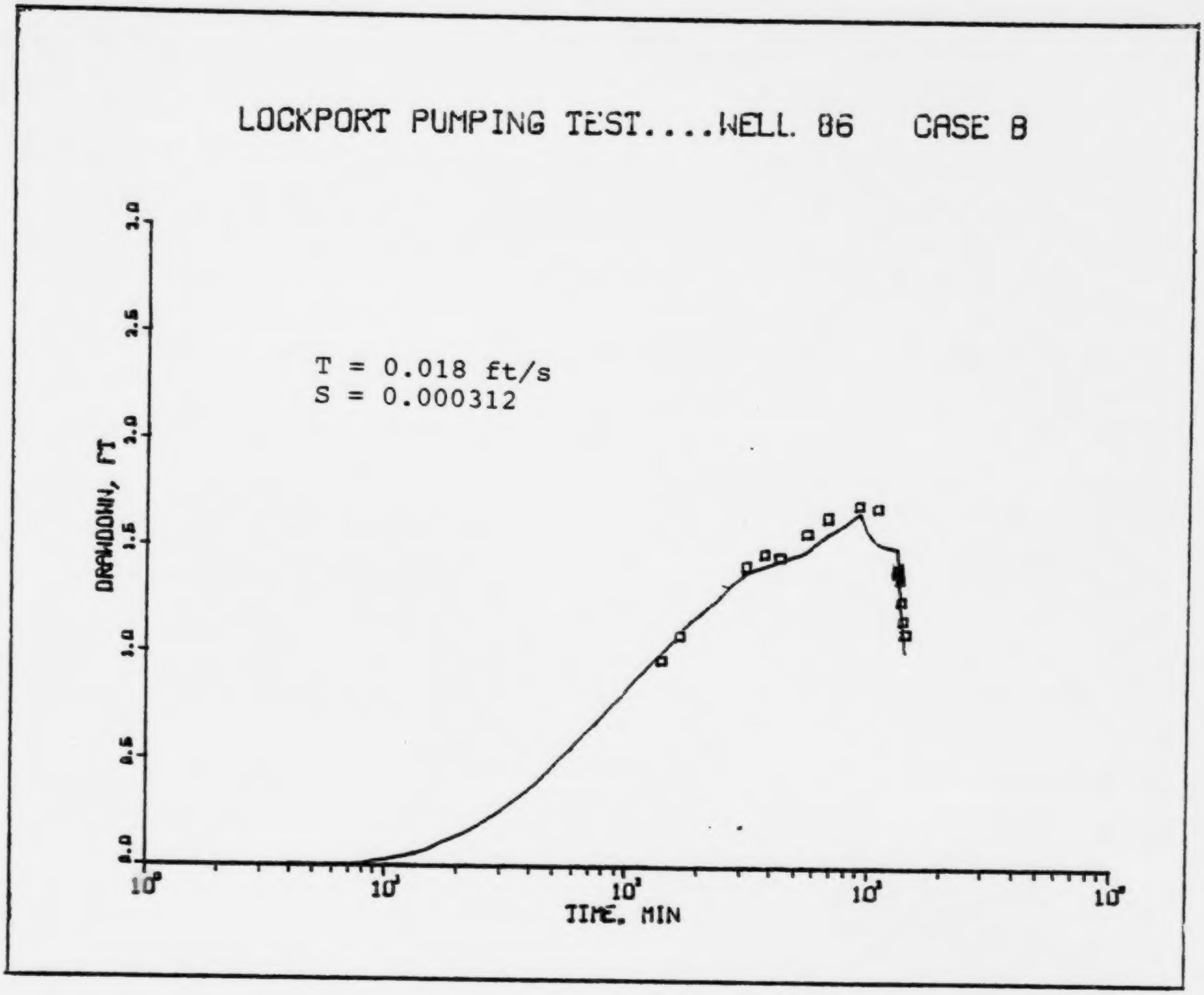

Figure C.23 Plot of Well 86 of observed drawdowns and theoretical drawdowns using T and S fitted to data from this well only.

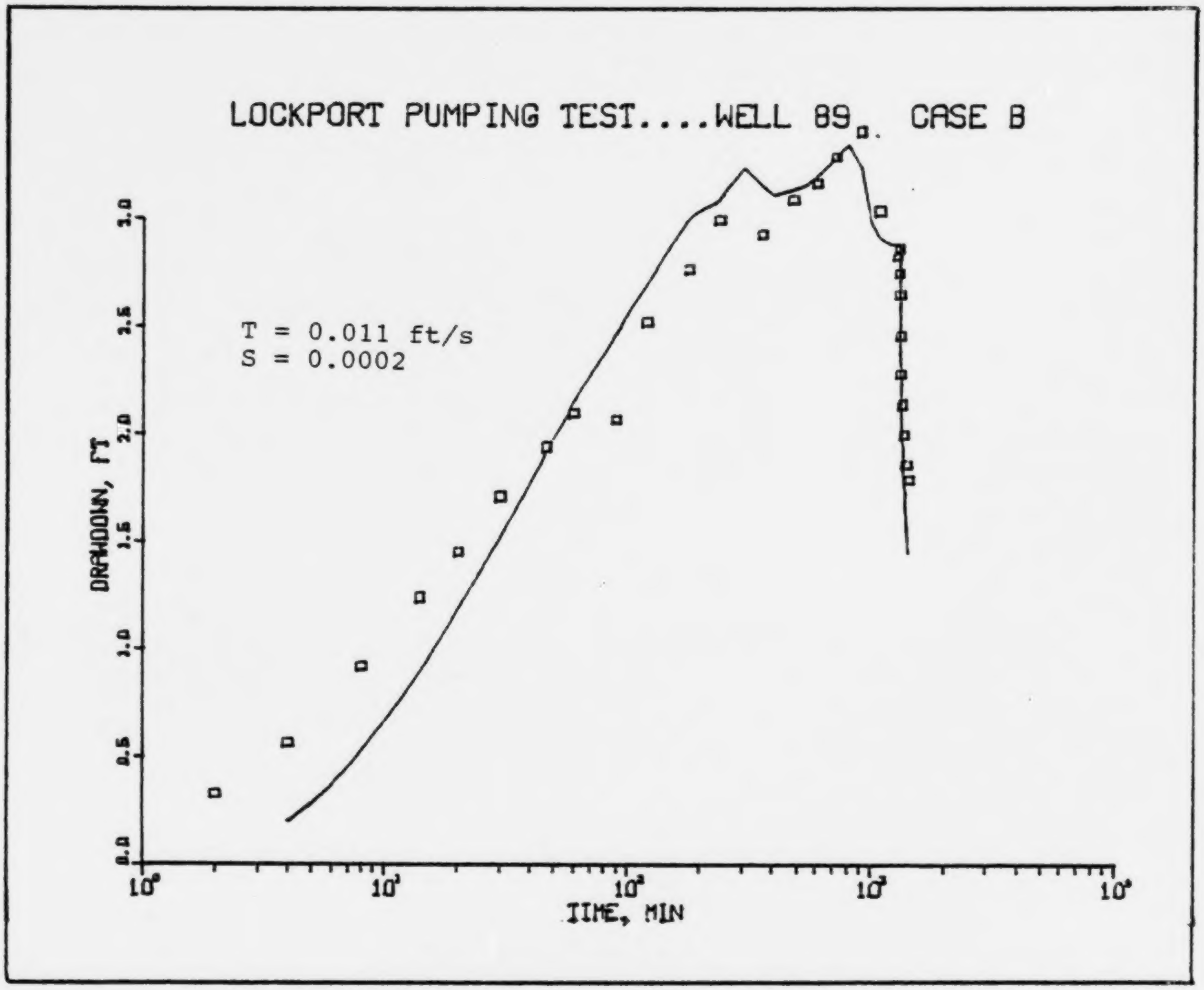

Figure C.24 Plot of Well 89 of observed drawdowns and theoretical drawdowns using T and S fitted to data from this well only.

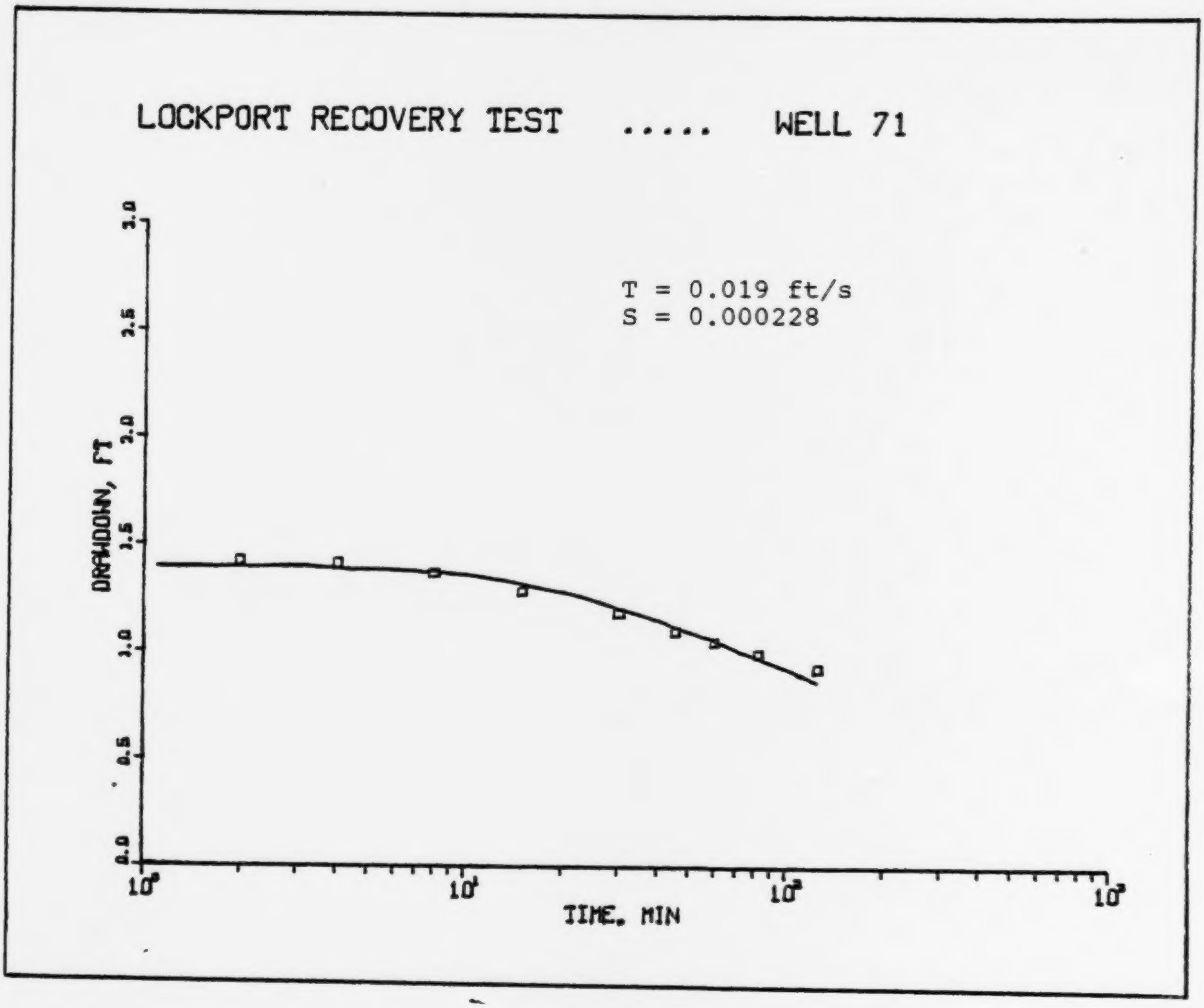

Figure C.25 Plot of Well 71 of observed drawdowns and theoretical drawdowns using T and S fitted to the recovery portion of the data for this well only.

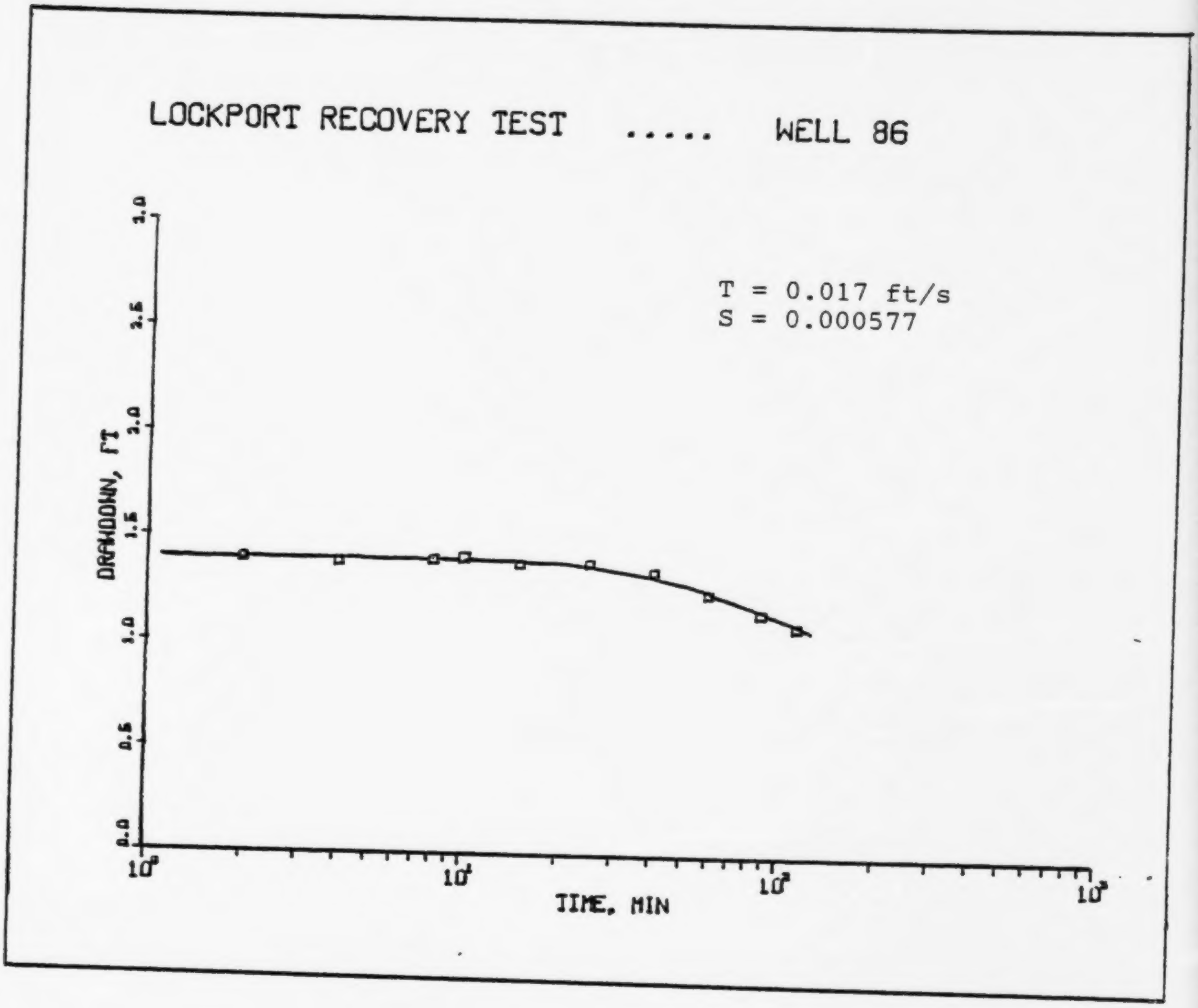

Figure C.26 Plot of Well 86 of observed drawdowns and theoretical drawdowns using T and S fitted to the recovery portion of the data for this well only.

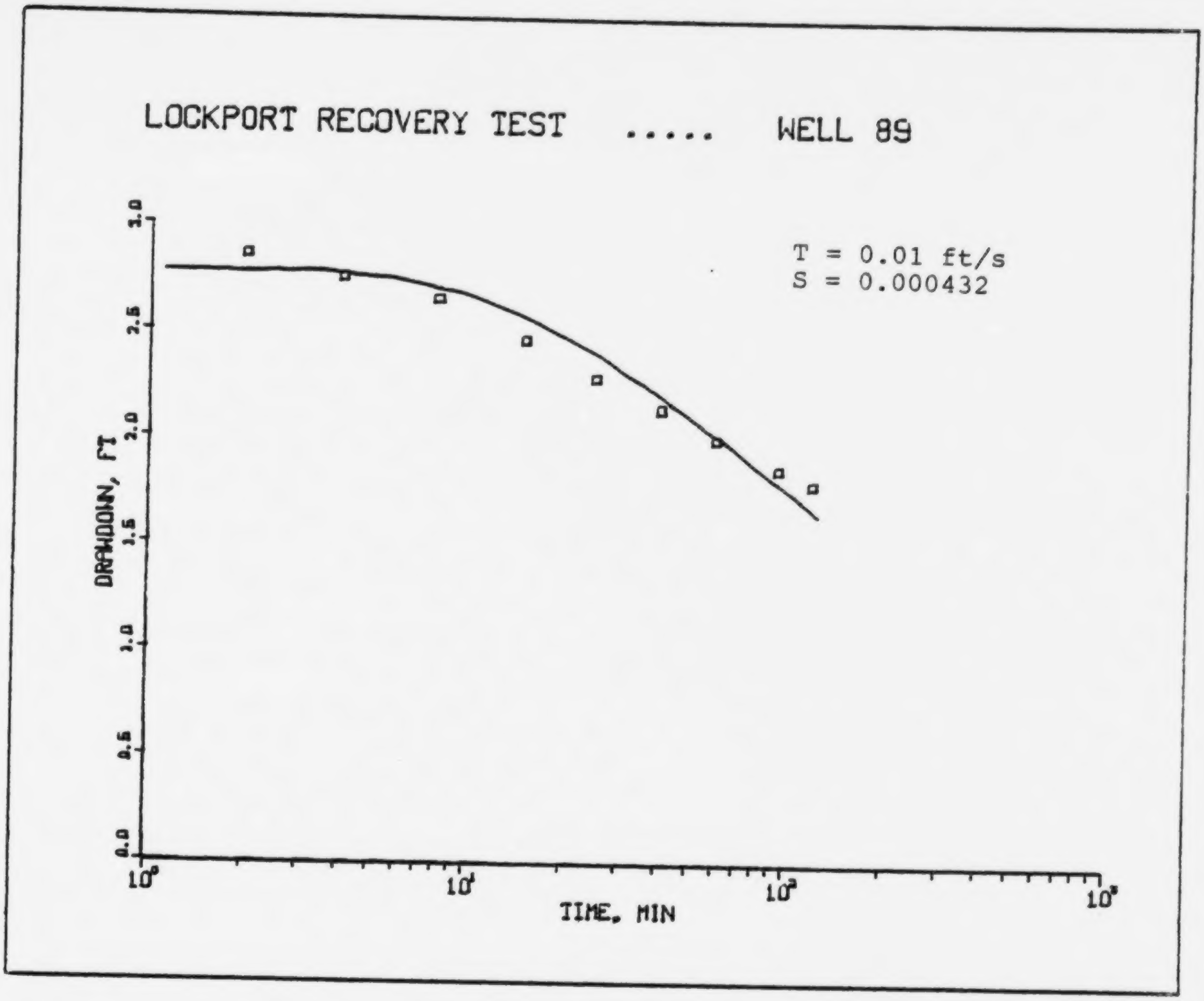

Figure C.27 Plot of Well 89 of observed drawdowns and theoretical drawdowns using T and S fitted to the recovery portion of the data for this well only.

APPENDIX D. LISTING OF COMPUTER MODEL, DATA, AND OUTPUT

As part of our contract, we are to provide the prime contractor listings of the program used, input data and computed results. The program selected for this study is that in Trescott, et al. (1976). The model is described in detail in the original reference. The code was developed on an IBM machine, so it was necessary to make the required changes to allow compilation on a CDC machine, which is what was used in this study.

In addition, there is a direct solution scheme described in Larson (1978) which is designed to replace one of the subroutines in the original program described in Trescott, et al. (1976). We felt this solution scheme would be helpful since it solves nonlinear problems (such as water-table conditions) better than the original program. Therefore, we merged this subroutine with the original program and converted the code to run on a CDC machine.

To aid in the use of the program, several input/output modifications were also performed. The first involved using free format for all two-dimensional (I,J) array data (see Trescott, et al., 1976, pp. 53-54). Input data for these arrays, therefore, consists of a string of values separated by one or more blanks, or by a comma. To repeat a value, an integer repeat constant is followed by an asterisk and the constant to be repeated. A slash is used to indicate "next card". Finally, to allow the determination of spatially distributed leakage, evapotranspiration and constant head fluxes, values for these were allowed to be printed on a node by node basis.

Included in this appendix are (1) a listing of the two-dimensional ground-water flow code used in this study, (2) input data in free format for run 1 of the Lockport Dolomite model, (3) output from run 1 of the Lockport Dolomite model, (4) input in free format for a typical run from the shallow system model, and (5) the corresponding output from the shallow system model.

D.1 Listing of Two-Dimensional Flow Model

```
      PROGRAM MODEL(INPUT,OUTPUT,PUNCH,TAPE2,TAPE4,                      GS2M      2
     1TAPE5=INPUT,TAPE6=OUTPUT,TAPE7=PUNCH)                              GS2M      3
C     ****************************************************************** GS2M      4
C                        FINITE-DIFFERENCE MODEL                         GS2M      5
C                                  FOR                                   GS2M      6
C                   SIMULATION OF GROUND-WATER FLOW                      GS2M      7
C                          IN TWO DIMENSIONS                             GS2M      8
C                                                                        GS2M      9
C          BY P. C. TRESCOTT, G. F. PINDER AND S. P. LARSON              GS2M     10
C                      U. S. GEOLOGICAL SURVEY                           GS2M     11
C                          SEPTEMBER, 1975                               GS2M     12
C     ****************************************************************** GS2M     13
C     MAIN PROGRAM TO DIMENSION DIGITAL MODEL AND CONTROL SEQUENCE       GS2M     14
C     OF COMPUTATIONS                                                    GS2M     15
C     ------------------------------------------------------------------ GS2M     16
C     SPECIFICATIONS:                                                    GS2M     17
      REAL KEEP,M,HEADNG(32)                                             GS2M     18
      INTEGER R,P,PU,DIML,DIMW,CHK,WATER,CONVRT,EVAP,CHCK,PNCH,NUM,HEAD, GS2M     19
     1CONTR,LEAK,RECH,SIP,ADI                                            GS2M     20
C                                                                        GS2M     21
      DIMENSION Y(40000),L(37),IFMT1(9),IFMT2(9),IFMT3(9),NAME(99)       LKPR8     1
C                                                                        GS2M     23
      COMMON /SARRAY/ VF4(11),CHK(15),IH                                 GS2M     24
      COMMON /SPARAM/ WATER,CONVRT,EVAP,CHCK,PNCH,NUM,HEAD,CONTR,EROR,LE GS2M     25
     1AK,RECH,SIP,U,SS,TT,TMIN,ETDIST,QET,ERR,TMAX,CDLT,HMAX,YDIM,WIDTH, GS2M     26
     2NUMS,LSOR,ADI,DELT,SUM,SUMP,SUBS,STORE,TEST,ETQB,ETQD,FACTX,FACTY, GS2M     27
     3IERR,KOUNT,IFINAL,NUMT,KT,KP,NPER,KTH,ITMAX,LENGTH,NWEL,NW,DIML,DI GS2M     28
     4MW,JNO1,INO1,R,P,PU,I,J,IDK1,IDK2,LKPR                             LKPR      1
C                                                                        GS2M     30
      DATA IFMT1/4H(1H0,4H,I5,,4H10E1,4H1.3/,4H(1H ,4H,5X,,4H10E1,4H1.3) GS2M     31
     1,4H)   /                                                           GS2M     32
      DATA IFMT2/4H(1H0,4H,I2,,4H2X,2,4H0F6.,4H1/(5,4HX,20,4HF6.1,4H))   GS2M     33
     1,4H    /                                                           GS2M     34
      DATA IFMT3/4H(1H0,4H,I5,,4H14F9,4H.5/(,4H1H ,,4H5X,1,4H4F9.,4H5))  GS2M     35
     1,4H    /                                                           GS2M     36
      DATA NAME/2*4H    ,4H STO,4HRAGE,4H COE,4HFFIC,4HIENT,4*4H    ,4H  GS2M     37
     1 T,4HRANS,4HMISS,4HIVIT,4HY   ,2*4H    ,4H   A,4HQUIF,4HER H,4HYD GS2M     38
     2RA,4HULIC,4H CON,4HDUCT,4HIVIT,4HY   ,4H    ,4H   A,4HQUIF,4HER B, GS2M     39
     34HASE ,4HELEV,4HATIO,4HN   ,3*4H    ,4H   S,4HPECI,4HFIC ,4HYIEL,4 GS2M     40
     4HD   ,4*4H    ,4HAQUI,4HFER ,4HTOP ,4HELEV,4HATIO,4HN   ,4H    ,4H GS2M     41
     5CONF,4HININ,4HG BE,4HD HY,4HDRAU,4HLIC ,4HCOND,4HUCTI,4HVITY,3*4H  GS2M     42
     6    ,4H RIV,4HER H,4HEAD ,4*4H    ,4H   C,4HONFI,4HNING,4H BED,4H T GS2M     43
     7HI,4HCKNE,4HSS  ,2*4H    ,4H   L,4HAND ,4HSURF,4HACE ,4HELEV,4HATI GS2M     44
     8O,4HN   ,3*4H    ,4H ARE,4HAL R,4HECHA,4HRGE ,4HRATE,2*4H    /     GS2M     45
C                                                                        GS2M     46
C     .................................................................. GS2M     47
C                                                                        GS2M     48
C     ---READ TITLE,PROGRAM OPTIONS AND PROGRAM SIZE---                  GS2M     49
      R=5                                                                GS2M     50
      P=6                                                                GS2M     51
   10 READ (R,370) HEADNG                                                GS2M     52
      WRITE (P,360) HEADNG                                               GS2M     53
      READ (R,380) WATER,LEAK,CONVRT,EVAP,RECH,NUMS,CHCK,PNCH,IDK1,IDK2, GS2M     54
     1NUM,HEAD,LKPR                                                      LKPR      2
      WRITE (P,390) WATER,LEAK,CONVRT,EVAP,RECH,NUMS,CHCK,PNCH,IDK1,IDK2 GS2M     56
     1,NUM,HEAD                                                          GS2M     57
      IF(LKPR.EQ.0) GO TO 15                                             LKPR      3
      WRITE(P,400) LKPR                                                  LKPR      4
   15 CONTINUE                                                           LKPR      5
      IF (NUMS.EQ.CHK(11).OR.NUMS.EQ.CHK(12).OR.NUMS.EQ.CHK(13)) GO TO 2 GS2M     58
     10                                                                  GS2M     59
      WRITE (P,350)                                                      GS2M     60
      STOP                                                               GS2M     61
   20 READ (R,320) DIML,DIMW,NW,ITMAX                                    GS2M     62
```

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```
      WRITE (P,340) DIML,DIMW,NW,ITMAX
C
C     ---COMPUTE DIMENSIONS FOR ARRAYS---
      IZ=DIML
      JZ=DIMW
      IW=MAX0(1,NW)
      IMAX=MAX0(DIML,DIMW)
      ISIZ=DIML*DIMW
      ISUM=  ISIZ+1
      IMX1=ITMAX+1
      L(1)=1
      DO 30 I=2,4
      L(I)=ISUM
   30 ISUM=ISUM+  IMAX
      DO 40 I=5,16
      L(I)=ISUM
   40 ISUM=ISUM+ISIZ
      IF (WATER.NE.CHK(2)) GO TO 60
      DO 50 I=17,19
      L(I)=ISUM
   50 ISUM=ISUM+ISIZ
      IP=DIML
      JP=DIMW
      GO TO 80
   60 DO 70 I=17,19
      L(I)=ISUM
   70 ISUM=ISUM+1
      IP=1
      JP=1
   80 IF (LEAK.NE.CHK(9)) GO TO 100
      DO 90 I=20,22
      L(I)=ISUM
   90 ISUM=ISUM+ISIZ
      IR=DIML
      JR=DIMW
      GO TO 120
  100 DO 110 I=20,22
      L(I)=ISUM
  110 ISUM=ISUM+1
      IR=1
      JR=1
  120 IF (CONVRT.NE.CHK(7)) GO TO 130
      L(23)=ISUM
      ISUM=ISUM+ISIZ
      IC=DIML
      JC=DIMW
      GO TO 140
  130 L(23)=ISUM
      ISUM=ISUM+1
      IC=1
      JC=1
  140 IF (EVAP.NE.CHK(6)) GO TO 150
      L(24)=ISUM
      ISUM=ISUM+ISIZ
      IL=DIML
      JL=DIMW
      GO TO 160
  150 L(24)=ISUM
      ISUM=ISUM+1
      IL=1
      JL=1
  160 IF (NUMS.NE.CHK(11)) GO TO 180
      DO 170 I=25,28
      L(I)=ISUM
  170 ISUM=ISUM+ISIZ
      IS=DIML
      JS=DIMW
      GO TO 200
  180 DO 190 I=25,28
      L(I)=ISUM
  190 ISUM=ISUM+1
      IS=1
      JS=1
  200 DO 210 I=29,31
      L(I)=ISUM
  210 ISUM=ISUM+DIMW
      DO 220 I=32,33
      L(I)=ISUM
  220 ISUM=ISUM+DIML
      L(34)=ISUM
      ISUM=ISUM+IH
      L(35)=ISUM
      ISUM=ISUM+2*IH
  230 L(36)=ISUM
      ISUM=ISUM+  IMAX
      L(37)=ISUM
      ISUM=ISUM+IMX1
      WRITE (P,330) ISUM
C
C     ..........................................................................
C
C     ---START COMPUTATIONS---
C     ************************
C     ---READ AND WRITE DATA FOR GROUPS II AND III---
      IHH=IH
      CALL DATAI(Y(L(1)),Y(L(7)),Y(L(8)),Y(L(9)),
     1Y(L(10)),Y(L(11)),Y(L(13)),Y(L(14)),Y(L(15)),Y(L(16)),
     2Y(L(17)),Y(L(20)),Y(L(21)),Y(L(22)),Y(L(29)),Y(L(32)),
     3Y(L(34)),Y(L(35)),IZ,JZ,IP,JP,IR,JR,IC,JC,IL,JL,IHH)
      CALL ARRAY(Y(L(12)),IFMT3,NAME(1),2,DIML,DIMW)
      IF (WATER.EQ.CHK(2)) GO TO 240
      CALL ARRAY(Y(L(9)),IFMT3,NAME(10),3,DIML,DIMW)
      GO TO 250
  240 CALL ARRAY(Y(L(17)),IFMT1,NAME(19),4,DIML,DIMW)
      CALL ARRAY(Y(L(18)),IFMT2,NAME(28),5,DIML,DIMW)
      CALL ARRAY(Y(L(19)),IFMT3,NAME(37),6,DIML,DIMW)
  250 IF (CONVRT.EQ.CHK(7)) CALL ARRAY(Y(L(23)),IFMT2,NAME(46),7,
     1 DIML,DIMW)
      IF (LEAK.NE.CHK(9)) GO TO 260
      CALL ARRAY(Y(L(20)),IFMT1,NAME(55),8,DIML,DIMW)
      CALL ARRAY(Y(L(21)),IFMT2,NAME(64),9,DIML,DIMW)
      CALL ARRAY(Y(L(22)),IFMT2,NAME(73),10,DIML,DIMW)
  260 IF (EVAP.EQ.CHK(6)) CALL ARRAY(Y(L(24)),IFMT2,NAME(82),11,
     1 DIML,DIMW)
      IF (RECH.EQ.CHK(10)) CALL ARRAY(Y(L(13)),IFMT1,NAME(91),12,
     1 DIML,DIMW)
      CALL MDAT(Y(L(1)),Y(L(7)),Y(L(8)),Y(L(9)),Y(L(10)),Y(L(11)),
     1Y(L(13)),Y(L(14)),Y(L(15)),Y(L(16)),Y(L(17)),
     2Y(L(20)),Y(L(21)),Y(L(22)),Y(L(29)),Y(L(32)),Y(L(34)),
     3Y(L(35)),IZ,JZ,IP,JP,IR,JR,IC,JC,IL,JL,IHH)
C
C     ---INITIALIZE TRANSMISSIVITY VALUES IN WATER TABLE PROBLEM---
      KT=0
      IF(WATER.EQ.CHK(2)) CALL TRANS(Y(L(1)),Y(L(5)),
     1Y(L(7)),Y(L(8)),Y(L(9)),Y(L(10)),Y(L(11)),Y(L(12)),Y(L(13)),
     2Y(L(14)),Y(L(15)),Y(L(16)),Y(L(17)),Y(L(18)),Y(L(19)),Y(L(20)),
     3Y(L(21)),Y(L(22)),Y(L(23)),Y(L(24)),Y(L(29)),Y(L(30)),
     4Y(L(32)),Y(L(34)),Y(L(35)),Y(L(37)))
C
C     ---COMPUTE ITERATION PARAMETERS---
      IF(NUMS.EQ.CHK(11)) CALL ITER1(Y(L(1)),Y(L(4)),Y(L(5)),Y(L(6)),
     1Y(L(7)),Y(L(9)),Y(L(12)),Y(L(13)),Y(L(14)),Y(L(15)),Y(L(16)),
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     2Y(L(25)),Y(L(26)),Y(L(27)),Y(L(28)),Y(L(29)),Y(L(32)),Y(L(37)),
     3Y(L(10)),Y(L(11)),Y(L(24)),Y(L(19)),Y(L(23)),Y(L(20)),Y(L(22)),
     4Y(L(21)),Y(L(8)),Y(L(17)),Y(L(18)),Y(L(30)),Y(L(34)),Y(L(35)))
      IF (NUMS.EQ.CHK(12)) CALL ITER2
     1(Y(L(1)),Y(L(2)),Y(L(3)),Y(L(4)),Y(L(5)),Y(L(6)),Y(L(7)),
     2Y(L(9)),Y(L(12)),Y(L(13)),Y(L(14)),Y(L(15)),Y(L(16)),Y(L(29)),
     3Y(L(31)),Y(L(32)),Y(L(33)),Y(L(37)),Y(L(10)),Y(L(11)),Y(L(24)),
     4Y(L(19)),Y(L(23)),Y(L(20)),Y(L(22)),Y(L(21)),Y(L(8)),Y(L(17)),
     5Y(L(18)),Y(L(30)),Y(L(34)),Y(L(35)))
      IF (NUMS.EQ.CHK(13)) CALL ITER3
     1(Y(L(1)),Y(L(2)),Y(L(3)),Y(L(4)),Y(L(5)),Y(L(6)),Y(L(7)),Y(L(9)),
     2Y(L(12)),Y(L(13)),Y(L(14)),Y(L(15)),Y(L(16)),Y(L(29)),Y(L(32)),
     3Y(L(36)),Y(L(37)),Y(L(10)),Y(L(11)),Y(L(24)),Y(L(19)),Y(L(23)),
     4Y(L(20)),Y(L(22)),Y(L(21)),Y(L(8)),Y(L(17)),Y(L(18)),Y(L(30)),
     5Y(L(34)),Y(L(35)))
C
C     ---INITIALIZE PARAMETERS FOR ALPHAMERIC MAP---
      IF(CONTR.EQ.CHK(3)) CALL MAP(Y(L(1)),Y(L(8)),Y(L(9)),Y(L(12)),
     1Y(L(14)),Y(L(29)),Y(L(32)),0)
C
C     ---COMPUTE T COEFFICIENTS FOR ARTESIAN PROBLEM---
      IF(WATER.NE.CHK(2)) CALL TCOF(Y(L(1)),Y(L(5)),Y(L(7)),
     1Y(L(8)),Y(L(9)),Y(L(10)),Y(L(11)),Y(L(12)),Y(L(13)),Y(L(14)),
     2Y(L(15)),Y(L(16)),Y(L(17)),Y(L(18)),Y(L(9)),Y(L(20)),
     3Y(L(21)),Y(L(22)),Y(L(23)),Y(L(24)),Y(L(29)),Y(L(30)),Y(L(32))
     4,Y(L(34)),Y(L(35)),Y(L(37)))
C
C     ---READ TIME PARAMETERS AND PUMPING DATA FOR A NEW PUMPING PERIOD-
  270 CALL NEWPER(Y(L(1)),Y(L(7)),Y(L(8)),Y(L(9)),Y(L(10)),Y(L(11)),
     1Y(L(13)),Y(L(14)),Y(L(15)),Y(L(16)),Y(L(17)),Y(L(20)),Y(L(21)),
     2Y(L(22)),Y(L(29)),Y(L(32)),Y(L(34)),Y(L(35)),
     3IZ,JZ,IP,JP,IR,JR,IC,JC,IL,JL,IHH)
C
      KT=0
      IFINAL=0
      IERR=0
C
C     ---START NEW TIME STEP COMPUTATIONS---
  280 CALL NEWSTP(Y(L(1)),Y(L(5)),Y(L(7)),Y(L(8)),Y(L(9)),Y(L(10)),
     1Y(L(11)),Y(L(12)),Y(L(13)),Y(L(14)),Y(L(15)),Y(L(17)),Y(L(18)),
     2Y(L(19)),Y(L(20)),Y(L(21)),Y(L(22)),Y(L(23)),Y(L(24)),Y(L(29)),
     3Y(L(30)),Y(L(32)),Y(L(34)),Y(L(35)),Y(L(37)))
C
C     ---COMPUTE TRANSIENT PART OF LEAKAGE TERM---
      IF (LEAK.EQ.CHK(9).AND.SS.NE.0.) CALL CLAY
     1(Y(L(1)),Y(L(5)),Y(L(7)),Y(L(8)),Y(L(9)),Y(L(10)),
     2Y(L(11 )),Y(L(12)),Y(L(13)),Y(L(14)),Y(L(15)),Y(L(16)),
     3Y(L(17)),Y(L(18)),Y(L(19)),Y(L(20)),Y(L(21)),Y(L(22)),Y(L(23)),
     4Y(L(24)),Y(L(29)),Y(L(30)),Y(L(32)),Y(L(34)),Y(L(35)),Y(L(37)))
C
C     ---ENTER APPROPIATE SOLUTION ROUTINE AND COMPUTE SOLUTION---
      IF (NUMS.EQ.CHK(11)) CALL NEWITA
     1(Y(L(1)),Y(L(4)),Y(L(5)),Y(L(6)),Y(L(7)),Y(L(9)),Y(L(12)),
     2Y(L(13)),Y(L(14)),Y(L(15)),Y(L(16)),Y(L(25)),Y(L(26)),Y(L(27)),
     3Y(L(28)),Y(L(29)),Y(L(32)),Y(L(37)),Y(L(10)),Y(L(11)),Y(L(24)),
     4Y(L(19)),Y(L(23)),Y(L(20)),Y(L(22)),Y(L(21)),Y(L(8)),Y(L(17)),
     5Y(L(18)),Y(L(30)),Y(L(34)),Y(L(35)))
      IF (NUMS.EQ.CHK(12)) CALL NEWITB
     1(Y(L(1)),Y(L(2)),Y(L(3)),Y(L(4)),Y(L(5)),Y(L(6)),Y(L(7)),Y(L(9)),
     2Y(L(12)),Y(L(13)),Y(L(14)),Y(L(15)),Y(L(16)),Y(L(29)),Y(L(31)),
     3Y(L(32)),Y(L(33)),Y(L(37)),Y(L(10)),Y(L(11)),Y(L(24)),Y(L(19)),
     4Y(L(23)),Y(L(20)),Y(L(22)),Y(L(21)),Y(L(8)),Y(L(17)),Y(L(18)),
     5Y(L(30)),Y(L(34)),Y(L(35)))
      IF (NUMS.EQ.CHK(13)) CALL NEWITC
     1(Y(L(1)),Y(L(2)),Y(L(3)),Y(L(4)),Y(L(5)),Y(L(6)),Y(L(7)),Y(L(9)),
     2Y(L(12)),Y(L(13)),Y(L(14)),Y(L(15)),Y(L(16)),Y(L(29)),Y(L(32)),
     3Y(L(36)),Y(L(37)),Y(L(10)),Y(L(11)),Y(L(24)),Y(L(19)),Y(L(23)),     GS2M     261
     4Y(L(20)),Y(L(22)),Y(L(21)),Y(L(8)),Y(L(17)),Y(L(18)),Y(L(30)),      GS2M     262
     5Y(L(34)),Y(L(35)))                                                  GS2M     263
C                                                                         GS2M     264
C     ---CHECK FOR STEADY STATE AND PRINT OUTPUT AT DESIGNATED            GS2M     265
C     TIME STEPS---                                                       GS2M     266
      CALL STEADY(Y(L(1)),Y(L(5)),Y(L(7)),Y(L(8)),Y(L(9)),Y(L(10)),       GS2M     267
     1Y(L(11)),Y(L(12)),Y(L(13)),Y(L(14)),Y(L(15)),Y(L(17)),Y(L(18)),     GS2M     268
     2Y(L(19)),Y(L(20)),Y(L(21)),Y(L(22)),Y(L(23)),Y(L(24)),Y(L(29)),     GS2M     269
     3Y(L(30)),Y(L(32)),Y(L(34)),Y(L(35)),Y(L(37)))                       GS2M     270
C                                                                         GS2M     271
C     ---LAST TIME STEP IN PUMPING PERIOD @---                            GS2M     272
      IF (IFINAL.NE.1) GO TO 280                                          GS2M     273
C                                                                         GS2M     274
C     ---CHECK FOR NEW PUMPING PERIOD---                                  GS2M     275
      IF (KP.LT.NPER) GO TO 270                                           GS2M     276
C                                                                         GS2M     277
C     ---DISK OUTPUT IF DESIRED---                                        GS2M     278
      IF (IDK2.NE.CHK(15)) GO TO 290                                      GS2M     279
      CALL DISK(Y(L(1)),Y(L(5)),Y(L(7)),Y(L(8)),Y(L(9)),Y(L(10)),         GS2M     280
     1Y(L(11)),Y(L(12)),Y(L(13)),Y(L(14)),Y(L(15)),Y(L(17)),Y(L(18)),     GS2M     281
     2Y(L(19)),Y(L(20)),Y(L(21)),Y(L(22)), Y(L(22)),Y(L(23)),Y(L(24)),    GS2M     282
     3Y(L(29)),Y(L(30)),Y(L(32)),Y(L(34)),Y(L(35)),Y(L(37)))              GS2M     283
C                                                                         GS2M     284
C     ---PUNCHED OUTPUT IF DESIRED---                                     GS2M     285
  290 IF (PNCH.NE.CHK(1)) GO TO 300                                       GS2M     286
      CALL PUNCH(Y(L(1)),Y(L(5)),Y(L(7)),Y(L(8)),Y(L(9)),Y(L(10)),        GS2M     287
     1Y(L(11)),Y(L(12)),Y(L(13)),Y(L(14)),Y(L(15)),Y(L(17)),Y(L(18)),     GS2M     288
     2Y(L(19)),Y(L(20)),Y(L(21)),Y(L(22)),Y(L(23)),Y(L(24)),Y(L(29)),     GS2M     289
     3Y(L(30)),Y(L(32)),Y(L(34)),Y(L(35)),Y(L(37)))                       GS2M     290
C                                                                         GS2M     291
C     ---CHECK FOR NEW PROBLEM---                                         GS2M     292
  300 READ (R,320         ) NEXT                                          GS2M     293
  309 IF (NEXT.EQ.0) GO TO 10                                             GS2M     294
  310 STOP                                                                GS2M     295
C     ................................................................... GS2M     296
C                                                                         GS2M     297
C     ---FORMATS---                                                       GS2M     298
C     ------------------------------------------------------------------- GS2M     299
C                                                                         GS2M     300
C                                                                         GS2M     301
  320 FORMAT (4I10)                                                       GS2M     302
  330 FORMAT (*0*,54X,*WORDS OF Y VECTOR USED =*,I7)                      GS2M     303
  340 FORMAT (*0*,62X,*NUMBER OF ROWS =*,I5/60X,*NUMBER OF COLUMNS =*,I5 GS2M     304
     1/9X,*NUMBER OF WELLS FOR WHICH DRAWDOWN IS COMPUTED AT A SPECIFIED GS2M     305
     2 RADIUS =*,I5,/,39X,*MAXIMUM PERMITTED NUMBER OF ITERATIONS =*,I5) GS2M     306
  350 FORMAT (*-*,36X,*NO EQUATION SOLVING SCHEME SPECIFIED, EXECUTION T GS2M     307
     1ERMINATED*/37X,58(1H*))                                             GS2M     308
  360 FORMAT (*1*,60X,*U. S. G. S.*//55X,*FINITE-DIFFERENCE MODEL*/65X,* GS2M     309
     1FOR*/51X,*SIMULATION OF GROUND-WATER FLOW*//60X,*JANUARY, 1975*//1 GS2M     310
     233(1H*)/*0*,32A4//133(1H*))                                         GS2M     311
  370 FORMAT (20A4)                                                       GS2M     312
  380 FORMAT(12(A4,1X),4I5)                                               LKPR       6
  390 FORMAT (*-SIMULATION OPTIONS:  *,13(A4,4X))                         GS2M     314
  400 FORMAT(/10X,*PRINT OUT GRID BLOCK FLUX EVERY*I5,2X,*TIME STEPS*/)  LKPR       7
      END                                                                 GS2M     315
      SUBROUTINE DATAI(PHI,STRT,SURI,T,TR,TC,  QRE,WELL,TL,SL,PERM,       GS2M     316
     1     RATE,RIVER,M,          DELX,DELY,WR,NWR                        GS2M     317
     2 ,IZ,JZ,IP,JP,IR,JR,IC,JC,IL,JL,IHH)                                GS2M     318
C     ------------------------------------------------------------------- GS2M     319
C     READ AND WRITE INPUT DATA                                           GS2M     320
C     ------------------------------------------------------------------- GS2M     321
C                                                                         GS2M     322
C     SPECIFICATIONS:                                                     GS2M     323
      REAL   M                                                            GS2M     324
      INTEGER R,P,PU,DIML,DIMW,CHK,WATER,CONVRT,EVAP,CHCK,PNCH,NUM,HEAD, GS2M     325
     1CONTR,LEAK,RECH,SIP,ADI,XLABEL,YLABEL
C                                                                       GS2M      326
      DIMENSION PHI(IZ,JZ), STRT(IZ,JZ), SURI(IZ,JZ), T(IZ,JZ), TR(IZ,JZ GS2M      327
     1), TC(IZ,JZ),           QRE(IZ,JZ), WELL(IZ,JZ), TL(IZ,JZ), SL(IZ, GS2M      328
     2JZ), PERM(IP,JP),                            RATE(IR,JR), RIVER(IR, GS2M      329
     3JR), M(IR,JR),                         DELX(JZ), DELY(IZ),WR(IHH) GS2M      330
     4,NWR(IHH,2)                                                       GS2M      331
C                                                                       GS2M      332
      COMMON /SARRAY/ VF4(11),CHK(15),IH                                GS2M      333
      COMMON /SPARAM/ WATER,CONVRT,EVAP,CHCK,PNCH,NUM,HEAD,CONTR,EROR,LE GS2M      334
     1AK,RECH,SIP,U,SS,TT,TMIN,ETDIST,QET,ERR,TMAX,CDLT,HMAX,YDIM,WIDTH, GS2M      335
     2NUMS,LSOR,ADI,DELT,SUM,SUMP,SUBS,STORE,TEST,ETQB,ETQD,FACTX,FACTY, GS2M      336
     3IERR,KOUNT,IFINAL,NUMT,KT,KP,NPER,KTH,ITMAX,LENGTH,NWEL,NW,DIML,DI GS2M      337
     4MW,JNO1,INO1,R,P,PU,I,J,IDK1,IDK2,LKPR                            GS2M      338
      COMMON /CK/ ETFLXT,STORT,QRET,CHST,CHDT,FLUXT,PUMPT,CFLUXT,FLXNT  LKPR        8
      COMMON /PR/ XLABEL(3),YLABEL(6),TITLE(5),XN1,MESUR,PRNT(122),BLANK GS2M      340
     1(60),DIGIT(122),VF1(6),VF2(6),VF3(7),XSCALE,DINCH,SYM(17),XN(100), GS2M      341
     2YN(13),NA(4),N1,N2,N3,YSCALE,FACT1,FACT2                          GS2M      342
      DIMENSION DUM1(60)                                                GS2M      343
C     ..................................................................LKPR2       1
C     ********************............................................. GS2M      344
      ENTRY DATAIN                                                      GS2M      345
C     ********************                                              GS2M      346
C                                                                       GS2M      347
C     ---READ AND WRITE SCALAR PARAMETERS---                            GS2M      348
      READ (R,500) CONTR,XSCALE,YSCALE,DINCH,FACT1,FACT2,MESUR          GS2M      349
      IF (CONTR.EQ.CHK(3)) WRITE (P,610) XSCALE,YSCALE,MESUR,MESUR,DINCH GS2M      350
     1,FACT1,FACT2                                                      GS2M      351
      READ (R,491) NPER,KTH,ERR,EROR,SS,QET,ETDIST,LENGTH,HMAX,FACTX,FAC GS2M      352
     1TY                                                                GS2M      353
      IF (ETDIST.LE.0.) ETDIST=1.                                       GS2M      354
      WRITE (P,520) NPER,KTH,ERR,EROR,SS,QET,ETDIST,FACTX,FACTY         GS2M      355
C                                                                       GS2M      356
C     ---READ CUMULATIVE MASS BALANCE PARAMETERS---                     GS2M      357
      READ (R,600) SUM,SUMP,PUMPT,CFLUXT,QRET,CHST,CHDT,FLUXT,STORT,ETFL GS2M      358
     1XT,FLXNT                                                          GS2M      359
      IF (IDK1.EQ.CHK(14)) GO TO 20                                     GS2M      360
      IF (SUM.EQ.0.0) GO TO 40                                          GS2M      361
      WRITE (P,480) SUM                                                 GS2M      362
C     ..................................................................GS2M      363
C     ..................................................................GS2M      364
C     ---READ DATA TO CONTINUE PREVIOUS COMPUTATIONS READ HERE---       GS2M      365
C     ------FROM CARDS:                                                 GS2M      366
      DO 10 I=1,DIML                                                    GS2M      367
      READ (R,540) (PHI(I,J),J=1,DIMW)                                  GS2M      368
   10 WRITE (P,530) I,(PHI(I,J),J=1,DIMW)                               GS2M      369
      GO TO 40                                                          GS2M      370
C     ------READ AND WRITE DATA FROM UNIT 4 ON DISK RATHER THAN CARDS:  GS2M      371
   20 READ (4) PHI,SUM,SUMP,PUMPT,CFLUXT,QRET,CHST,CHDT,FLUXT,STORT,ETFL GS2M      372
     1XT,FLXNT                                                          GS2M      373
      WRITE (P,480) SUM                                                 GS2M      374
      DO 30 I=1,DIML                                                    GS2M      375
   30 WRITE (P,530) I,(PHI(I,J),J=1,DIMW)                               GS2M      376
      REWIND 4                                                          GS2M      377
C     ............................ STRT (STARTING HEAD) ............... GS2M      378
   40 READ (R,492) FACT,IVAR,IPRN,IRECS,IRECD                           GS2M      379
      IF(IRECS.EQ.1) GO TO 210                                          GS2M      380
      IF (IRECS.EQ.1) READ (2  ) STRT                                   GS2M      381
      IF ((IVAR.EQ.1.OR.IRECS.EQ.1).AND.IPRN.NE.1) WRITE (P,470)        GS2M      382
      DO 80 I=1,DIML                                                    GS2M      383
      IF (IVAR.EQ.1) READ(R,*)(STRT(I,J),J=1,DIMW)                      GS2M      384
      DO 70 J=1,DIMW                                                    LKPR7       1
      IF (IRECS.EQ.1) GO TO 60                                          GS2M      386
      IF (IVAR.NE.1) GO TO 50                                           GS2M      387
      STRT(I,J)=STRT(I,J)*FACT                                          GS2M      388
      GO TO 60                                                          GS2M      389
                                                                        GS2M      390
   50 STRT(I,J)=FACT                                                    GS2M     391
   60 SURI(I,J)=STRT(I,J)                                               GS2M     392
      T(I,J)=0.                                                         GS2M     393
      TL(I,J)=0.                                                        GS2M     394
      SL(I,J)=0.                                                        GS2M     395
      TR(I,J)=0.                                                        GS2M     396
      TC(I,J)=0.                                                        GS2M     397
      WELL(I,J)=0.0                                                     GS2M     398
      QRE(I,J)=0.                                                       GS2M     399
   70 IF (SUM.EQ.0.0.AND.IDK1.NE.CHK(14)) PHI(I,J)=STRT(I,J)            GS2M     400
   80 CONTINUE                                                          LKPR7      2
      IF (IVAR.EQ.0.AND.IRECS.EQ.0.OR.IPRN.EQ.1) GO TO 85               LKPR7      3
      DO 84 I=1,DIML                                                    LKPR7      4
   84 WRITE(P,530) I,(STRT(I,J),J=1,DIMW)                               LKPR7      5
   85 CONTINUE                                                          LKPR7      6
      IF (IVAR.NE.1.AND.IRECS.NE.1) WRITE (P,420) FACT                  GS2M     404
      IF (IRECD.EQ.1) WRITE (2  ) STRT                                  GS2M     405
      RETURN                                                            GS2M     406
C                                                                       GS2M     407
C     ---INSERT ZERO VALUES IN THE T OR PERM MATRIX AROUND THE          GS2M     408
C        BORDER OF THE MODEL---                                         GS2M     409
C     ***************                                                   GS2M     410
      ENTRY MDAT                                                        GS2M     411
C     **************                                                    GS2M     412
      DO 180 I=1,DIML                                                   GS2M     413
      DO 180 J=1,DIMW                                                   GS2M     414
      IF (WATER.EQ.CHK(2)) GO TO 170                                    GS2M     415
      IF (I.EQ.1.OR.I.EQ.DIML.OR.J.EQ.1.OR.J.EQ.DIMW) T(I,J)=0.         GS2M     416
      GO TO 180                                                         GS2M     417
  170 IF (I.EQ.1.OR.I.EQ.DIML.OR.J.EQ.1.OR.J.EQ.DIMW) PERM(I,J)=0.      GS2M     418
  180 CONTINUE                                                          GS2M     419
C     ................................... DELX,DELY ....................... GS2M     420
      READ (R,492) FACT,IVAR,IPRN,IRECS,IRECD                           GS2M     421
      IF (IVAR.EQ.1) READ (R,490) DELX                                  GS2M     422
      DO 200 J=1,DIMW                                                   GS2M     423
      IF (IVAR.NE.1) GO TO 190                                          GS2M     424
      DELX(J)=DELX(J)*FACT                                              GS2M     425
      GO TO 200                                                         GS2M     426
  190 DELX(J)=FACT                                                      GS2M     427
  200 CONTINUE                                                          GS2M     428
      GO TO 220                                                         GS2M     429
  210 READ(2) DELX                                                      GS2M     430
  220 IF(IRECS.EQ.1) WRITE(2) DELX                                      GS2M     431
      IF (IVAR.EQ.1.OR.IRECS.EQ.1.AND.IPRN.NE.1) WRITE (P,550) DELX     GS2M     432
      IF (IVAR.NE.1.AND.IRECS.NE.1) WRITE (P,450) FACT                  GS2M     433
      READ (R,492) FACT,IVAR,IPRN,IRECS,IRECD                           GS2M     434
      IF (IRECS.EQ.1) GO TO 250                                         GS2M     435
      IF (IVAR.EQ.1) READ (R,490) DELY                                  GS2M     436
      DO 240 I=1,DIML                                                   GS2M     437
      IF (IVAR.NE.1) GO TO 230                                          GS2M     438
      DELY(I)=DELY(I)*FACT                                              GS2M     439
      GO TO 240                                                         GS2M     440
  230 DELY(I)=FACT                                                      GS2M     441
  240 CONTINUE                                                          GS2M     442
      GO TO 260                                                         GS2M     443
  250 READ (2   ) DELY                                                  GS2M     444
  260 IF (IRECD.EQ.1) WRITE (2   ) DELY                                 GS2M     445
      IF (IVAR.EQ.1.OR.IRECS.EQ.1.AND.IPRN.NE.1) WRITE (P,560) DELY     GS2M     446
      IF (IVAR.NE.1.AND.IRECS.NE.1) WRITE (P,460) FACT                  GS2M     447
C                                                                       GS2M     448
C     ---INITIALIZE VARIABLES---                                        GS2M     449
      JNO1=DIMW-1                                                       GS2M     450
      INO1=DIML-1                                                       GS2M     451
      IF (LEAK.NE.CHK(9).OR.SS.NE.0.) GO TO 280                         GS2M     452
      DO 270 I=2,INO1                                                   GS2M     453
      DO 270 J=2,JNO1                                                   GS2M     454
      IF (M(I,J).EQ.0.) GO TO 270                                       GS2M     455
      TL(I,J)=RATE(I,J)/M(I,J)                                          GS2M     456
  270 CONTINUE                                                          GS2M     457
  280 ETQB=0.0                                                          GS2M     458
      ETQD=0.0                                                          GS2M     459
      SUBS=0.0                                                          GS2M     460
      U=1.0                                                             GS2M     461
      TT=0.0                                                            GS2M     462
      IM=MIN0(6*DIMW+4,124)                                             GS2M     463
      IM=(132-IM)/2                                                     GS2M     464
      VF4(3)=DIGIT(IM)                                                  GS2M     465
      VF4(8)=DIGIT(IM+5)                                                GS2M     466
      WIDTH=0.                                                          GS2M     467
      DO 290 J=2,JNO1                                                   GS2M     468
  290 WIDTH=WIDTH+DELX(J)                                               GS2M     469
      YDIM=0.                                                           GS2M     470
      DO 300 I=2,INO1                                                   GS2M     471
  300 YDIM=YDIM+DELY(I)                                                 GS2M     472
      RETURN                                                            GS2M     473
C     ............................................................... GS2M     474
C                                                                       GS2M     475
C     ---READ TIME PARAMETERS AND PUMPING DATA FOR A NEW PUMPING PERIOD- GS2M     476
C     *************************                                         GS2M     477
      ENTRY NEWPER                                                      GS2M     478
C     *************************                                         GS2M     479
C                                                                       GS2M     480
      READ(R,493) KP,KPM1,NWEL,TMAX,NUMT,CDLT,DELT,KRCH                 LKPR4      1
C                                                                       GS2M     482
C     ---COMPUTE ACTUAL DELT AND NUMT---                                GS2M     483
      DT=DELT/24.                                                       GS2M     484
      TM=0.0                                                            GS2M     485
      DO 310 I=1,NUMT                                                   GS2M     486
      DT=CDLT*DT                                                        GS2M     487
      TM=TM+DT                                                          GS2M     488
      IF (TM.GE.TMAX) GO TO 320                                         GS2M     489
  310 CONTINUE                                                          GS2M     490
      GO TO 330                                                         GS2M     491
  320 DELT=TMAX/TM*DELT                                                 GS2M     492
      NUMT=I                                                            GS2M     493
  330 WRITE (P,570) KP,TMAX,NUMT,DELT,CDLT                              GS2M     494
      DELT=DELT*3600.                                                   GS2M     495
      TMAX=TMAX*86400.                                                  GS2M     496
      IF(KRCH.EQ.0) GO TO 348                                           LKPR2      3
      WRITE (P,620)                                                     LKPR2      4
      READ (R,*) KCONS,CONRCH                                           LKPR3      1
      IF(KCONS.EQ.0) GO TO 344                                          LKPR3      2
      DO 342 I=1,DIML                                                   LKPR3      3
      DO 342 J=1,DIMW                                                   LKPR3      4
      N=I+(J-1)*DIML                                                    LKPR3      5
  342 QRE(N)=CONRCH                                                     LKPR3      6
      WRITE (P,650) CONRCH                                              LKPR3      7
      GO TO 348                                                         LKPR3      8
  344 CONTINUE                                                          LKPR3      9
      DO 346 I=1,DIML                                                   LKPR2      5
      READ (R,*) (DUM1(J),J=1,DIMW)                                     LKPR3     10
      WRITE (P,630) I                                                   LKPR2      7
      WRITE (P,640) (DUM1(J),J=1,DIMW)                                  LKPR2      8
      DO 346 J=1,DIMW                                                   LKPR2      9
      N=I+(J-1)*DIML                                                    LKPR2     10
      QRE(N)=DUM1(J)                                                    LKPR2     11
  346 CONTINUE                                                          LKPR2     12
  348 CONTINUE                                                          LKPR2     13
C                                                                       GS2M     497
C     ---INITIALIZE SUMP, STRT, SL, WELL AND WR---                      GS2M     498
      WRITE (P,580) NWEL                                                GS2M     499
      IF (KP.GT.KPM1) SUMP=0.                                           GS2M     500
      DO 350 I=1,DIML
      DO 350 J=1,DIMW                                                   GS2M     501
      IF (KP.EQ.KPM1) GO TO 340                                         GS2M     502
      STRT(I,J)=PHI(I,J)                                                GS2M     503
  340 IF (LEAK.NE.CHK(9)) GO TO 350                                     GS2M     504
      IF (M(I,J).EQ.0.) GO TO 350                                       GS2M     505
      SL(I,J)=RATE(I,J)/M(I,J)*(RIVER(I,J)-STRT(I,J))                   GS2M     506
  350 WELL(I,J)=0.                                                      GS2M     507
      IF (NW.EQ.0) GO TO 370                                            GS2M     508
      DO 360 I=1,NW                                                     GS2M     509
  360 WR(I)=0.                                                          GS2M     510
  370 IF (NWEL.EQ.0) GO TO 410                                          GS2M     511
C                                                                       GS2M     512
C     ---READ AND WRITE WELL PUMPING RATES AND WELL RADII---            GS2M     513
      KW=0                                                              GS2M     514
      DO 400 II=1,NWEL                                                  GS2M     515
      READ (R,491) I,J,WELL(I,J),RADIUS                                 GS2M     516
      IF (RADIUS.EQ.0.) GO TO 380                                       GS2M     517
      KW=KW+1                                                           GS2M     518
      IF (KW.GT.NW) GO TO 380                                           GS2M     519
      NWR(KW,1)=I                                                       GS2M     520
      NWR(KW,2)=J                                                       GS2M     521
      WR(KW)=RADIUS                                                     GS2M     522
      WRITE (P,590) I,J,WELL(I,J),WR(KW)                                GS2M     523
      GO TO 390                                                         GS2M     524
  380 WRITE (P,590) I,J,WELL(I,J)                                       GS2M     525
  390 WELL(I,J)=WELL(I,J)/(DELX(J)*DELY(I))                             GS2M     526
  400 CONTINUE                                                          GS2M     527
  410 RETURN                                                            GS2M     528
C     ................................................................. GS2M     529
C                                                                       GS2M     530
C     FORMATS:                                                          GS2M     531
C                                                                       GS2M     532
C     ----------------------------------------------------------------- GS2M     533
C                                                                       GS2M     534
C                                                                       GS2M     535
  420 FORMAT (*0*,63X,*STARTING HEAD =*,G15.7)                          GS2M     536
  430 FORMAT (*0*,41X,9A4,*=*,G15.7)                                    GS2M     537
  440 FORMAT (*1*,49X,9A4,/,65X,*MATRIX*,/,50X,36(*-*))                 GS2M     538
  450 FORMAT (*0*,72X,*DELX =*,G15.7)                                   GS2M     539
  460 FORMAT (*0*,72X,*DELY =*,G15.7)                                   GS2M     540
  470 FORMAT (*1*,60X,*STARTING HEAD MATRIX*/61X,20(*-*))               GS2M     541
  480 FORMAT (*1*,40X,* CONTINUATION - HEAD AFTER *,G20.7,* SEC PUMPING GS2M     542
     1*/42X,58(*-*))                                                    GS2M     543
  490 FORMAT (8G10.0)                                                   GS2M     544
  491 FORMAT(2I10,5F10.0,I10,/,3F10.0)                                  GS2M     545
  492 FORMAT(F10.0,4I10)                                                GS2M     546
  493 FORMAT(3I10,F10.0,I10,2F10.0,I10)                                 GS2M     547
  500 FORMAT (A4,6X,5G10.0,A8)                                          LKPRS      1
  510 FORMAT (20F4.0)                                                   GS2M     549
  520 FORMAT (*0*,51X,*NUMBER OF PUMPING PERIODS =*,I5/49X,*TIME STEPS B GS2M     550
     1ETWEEN PRINTOUTS =*,I5//51X,*ERROR CRITERION FOR CLOSURE =*,G15.7/ GS2M     551
     241X,*          STEADY STATE ERROR CRITERION =*,G15.7//44X,*SPECIFIC GS2M     552
     3 STORAGE OF CONFINING BED =*,G15.7/54X,*EVAPOTRANSPIRATION RATE =* GS2M     553
     4,G15.7/56X,*EFFECTIVE DEPTH OF ET =*,G15.7//22X,*MULTIPLICATION FA GS2M     554
     5CTOR FOR TRANSMISSIVITY IN X DIRECTION =*,G15.7/63X,*IN Y DIRECTIO GS2M     555
     6N =*,G15.7)                                                       GS2M     556
  530 FORMAT (*0*,I2,2X,20F6.1/(5X,20F6.1))                             GS2M     557
  540 FORMAT (8F10.4)                                                   GS2M     558
  550 FORMAT (1H1,46X,40HGRID SPACING IN PROTOTYPE IN X DIRECTION/47X,40 GS2M     559
     1(*-*)//(*0*,12F10.0))                                             GS2M     560
  560 FORMAT (1H-,46X,40HGRID SPACING IN PROTOTYPE IN Y DIRECTION/47X,40 GS2M     561
     1(*-*)//(*0*,12F10.0))                                             GS2M     562
  570 FORMAT (*-*,50X,*PUMPING PERIOD NO.*,I4,*:*,F10.2,* DAYS*/51X,38(* GS2M     563
     1-*)//53X,*NUMBER OF TIME STEPS=*,I6//59X,*DELT IN HOURS =*,F10.3// GS2M     564
     253X,*MULTIPLIER FOR DELT =*,F10.3)                                GS2M     565
                                                                        GS2M     566
  580 FORMAT (*-*,63X,I4,* WELLS*/65X,9(*-*)//50X,*I*,9X,*J    PUMPING R
     1ATE  WELL RADIUS*/)
  590 FORMAT (41X,2I10,2F13.2)
  600 FORMAT (4G20.10)
  610 FORMAT (*0*,30X,*ON ALPHAMERIC MAP:*/40X,*MULTIPLICATION FACTOR FO
     1R X DIMENSION =*,G15.7/40X,*MULTIPLICATION FACTOR FOR Y DIMENSION
     2=*,G15.7/55X,*MAP SCALE IN UNITS OF  *,A11/50X,*NUMBER OF *,A8,* P
     3ER INCH =*,G15.7/43X,*MULTIPLICATION FACTOR FOR DRAWDOWN =*,G15.7/
     44/X,*MULTIPLICATION FACTOR FOR HEAD =*,G15.7)
  620 FORMAT(//10X,*NEW RECHARGE DATA*)
  630 FORMAT(/10X,*ROW*,I5)
  640 FORMAT(2X,12G10.3)
  650 FORMAT(/10X,*UNIFORM RECHARGE*,10X,G12.5)
      END
      SUBROUTINE SOLVE1(PHI     ,TEMP,KEEP,PHE,STRT,T,S,QRE,WELL,TL,SL,D
     1EL,ETA,V,XI,DELX    ,DELY    ,TEST3,TR,TC,GRND,SY,TOP,RATE,M,RIVER
     2 ,SURI,PERM,BOTTOM,DON,WR,NWR)
C     ------------------------------------------------------------------
C      SOLUTION BY THE STRONGLY IMPLICIT PROCEDURE
C     ------------------------------------------------------------------
C
C     SPECIFICATIONS:
      REAL   KEEP,M
      INTEGER R,P,PU,DIML,DIMW,CHK,WATER,CONVRT,EVAP,CHCK,PNCH,NUM,HEAD,
     1CONTR,LEAK,RECH,SIP,IORDER(21),ADI
C
      DIMENSION PHI(1),                  TEMP(1), KEEP(1), PHE(1), STRT(1),
     1T(1), S(1), QRE(1), WELL(1), TL(1), SL(1), DEL(1), ETA(1), V(1), X
     2I(1), DELX(1),          DELY(1),            TEST3(1), TR(1), TC(1), GR
     3ND(1), SY(1), TOP(1), RATE(1), M(1), RIVER(1),RHOP(20)
     4 ,SURI(1),PERM(1),BOTTOM(1),DON(1),WR(1),NWR(1)
C
      COMMON /SARRAY/ VF4(11),CHK(15),IH
      COMMON /SPARAM/ WATER,CONVRT,EVAP,CHCK,PNCH,NUM,HEAD,CONTR,EROR,LE
     1AK,RECH,SIP,U,SS,TT,TMIN,ETDIST,GET,ERR,TMAX,CDLT,HMAX,YDIM,WIDTH,
     2NUMS,LSOR,ADI,DELT,SUM,SUMP,SUBS,STORE,TEST,ETQB,ETQD,FACTX,FACTY,
     3IERR,KOUNT,IFINAL,NUMT,KT,KP,NPER,KTH,ITMAX,LENGTH,NWEL,NW,DIML,DI
     4MW,JNO1,INO1,R,P,PU,I,J,IDK1,IDK2,LKPR
C     ..................................................................
C
C     ---COMPUTE AND PRINT ITERATION PARAMETERS---
C     ********************
      ENTRY ITER1
C     ********************
C     ---INITIALIZE ORDER OF ITERATION PARAMETERS (OR REPLACE WITH A
C     READ STATEMENT)---
      DATA IORDER/1,2,3,4,5,1,2,3,4,5,11*1/
      I2=INO1-1
      J2=JNO1-1
      L2=LENGTH/2
      PL2=L2-1.
      W=0.
      PI=0.
C
C     ---COMPUTE AVERAGE MAXIMUM PARAMETER FOR PROBLEM---
      DO 10 I=2,INO1
      DO 10 J=2,JNO1
      N=I+DIML*(J-1)
      IF (T(N).EQ.0.) GO TO 10
      PI=PI+1.
      DX=DELX(J)/WIDTH
      DY=DELY(I)/YDIM
      W=W+1.-AMIN1(2.*DX*DX/(1.+FACTY*DX*DX/(FACTX*DY*DY)),2.*DY*DY/(1.+
     1FACTX*DY*DY/(FACTY*DX*DX)))
   10 CONTINUE
      W=W/PI
```

```
C
C     ---COMPUTE PARAMETERS IN GEOMETRIC SEQUENCE---
      PJ=-1.
      DO 20 I=1,L2
      PJ=PJ+1.
   20 TEMP(I)=1.-(1.-W)**(PJ/PL2)
C
C     ---ORDER SEQUENCE OF PARAMETERS---
      DO 30 J=1,LENGTH
   30 RHOP(J)=TEMP(IORDER(J))
      WRITE (P,370) HMAX
      WRITE (P,380) LENGTH,(RHOP(J),J=1,LENGTH)
      RETURN
C     ..................................................................
C
C     ---INITIALIZE DATA FOR A NEW ITERATION---
   40 KOUNT=KOUNT+1
      IF (KOUNT.LE.ITMAX) GO TO 50
      WRITE (P,360)
      CALL TERM1(PHI,KEEP,STRT,SURI,T,TR,TC,S,QRE,WELL,TL,PERM,
     1 BOTTOM,SY,RATE,RIVER,M,TOP,GRND,DELX,DDN,DELY,WR,NWR,TEST3)
   50 IF (MOD(KOUNT,LENGTH)) 60,60,70
C     ************************
      ENTRY NEWITA
C     ************************
   60 NTH=0
   70 NTH=NTH+1
      W=RHOP(NTH)
      TEST3(KOUNT+1)=0.
      TEST=0.
      N=DIML*DIMW
      DO 80 I=1,N
      PHE(I)=PHI(I)
      DEL(I)=0.
      ETA(I)=0.
      V(I)=0.
   80 XI(I)=0.
      BIGI=0.0
C
C     ---COMPUTE TRANSMISSIVITY AND T COEFFICIENTS IN WATER TABLE
C     OR WATER TABLE-ARTESIAN SIMUATION---
      IF (WATER.NE.CHK(2)) GO TO 90
      CALL TRANS(PHI,KEEP,STRT,SURI,T,TR,TC,S,QRE,WELL,TL,SL,PERM,
     1 BOTTOM,SY,RATE,RIVER,M,TOP,GRND,DELX,DDN,DELY,WR,NWR,TEST3)
C
C     ---CHOOSE SIP NORMAL OR REVERSE ALGORITHM---
   90 IF (MOD(KOUNT,2)) 100,230,100
C     ..................................................................
C     ---ORDER EQUATIONS WITH ROW 1 FIRST - 3X3 EXAMPLE:
C              1 2 3
C              4 5 6
C              7 8 9
C     ..................................................................
  100 DO 210 I=2,IN01
      DO 210 J=2,JN01
      N=I+DIML*(J-1)
      NL=N-DIML
      NR=N+DIML
      NA=N-1
      NB=N+1
C
C     ---SKIP COMPUTATIONS IF NODE IS OUTSIDE AQUIFER BOUNDARY---
      IF (T(N).EQ.0..OR.S(N).LT.0.) GO TO 210
C
C     ---COMPUTE COEFFICIENTS---
      D=TR(NL)/DELX(J)
      F=TR(N)/DELX(J)                                                   GS2M     695
      B=TC(NA)/DELY(I)                                                  GS2M     696
      H=TC(N)/DELY(I)                                                   GS2M     697
      IF (EVAP.NE.CHK(6)) GO TO 120                                     GS2M     698
C                                                                       GS2M     699
C     ---COMPUTE EXPLICIT AND IMPLICIT PARTS OF ET RATE---              GS2M     700
      ETQB=0.                                                           GS2M     701
      ETQD=0.0                                                          GS2M     702
      IF (PHE(N).LE.GRND(N)-ETDIST) GO TO 120                           GS2M     703
      IF (PHE(N).GT.GRND(N)) GO TO 110                                  GS2M     704
      ETQB=QET/ETDIST                                                   GS2M     705
      ETQD=ETQB*(ETDIST-GRND(N))                                        GS2M     706
      GO TO 120                                                         GS2M     707
  110 ETQD=QET                                                          GS2M     708
C                                                                       GS2M     709
C     ---COMPUTE STORAGE TERM---                                        GS2M     710
  120 IF (CONVRT.EQ.CHK(7)) GO TO 130                                   GS2M     711
      RHO=S(N)/DELT                                                     GS2M     712
      IF (WATER.EQ.CHK(2)) RHO=SY(N)/DELT                               GS2M     713
      GO TO 200                                                         GS2M     714
C                                                                       GS2M     715
C     ---COMPUTE STORAGE COEFFICIENT FOR CONVERSION PROBLEM---          GS2M     716
  130 SUBS=0.0                                                          GS2M     717
      IF (KEEP(N).GE.TOP(N).AND.PHE(N).GE.TOP(N)) GO TO 170             GS2M     718
      IF (KEEP(N).LT.TOP(N).AND.PHE(N).LT.TOP(N)) GO TO 160             GS2M     719
      IF (KEEP(N)-PHE(N)) 140,150,150                                   GS2M     720
  140 SUBS=(SY(N)-S(N))/DELT*(KEEP(N)-TOP(N))                           GS2M     721
      GO TO 170                                                         GS2M     722
  150 SUBS=(S(N)-SY(N))/DELT*(KEEP(N)-TOP(N))                           GS2M     723
  160 RHO=SY(N)/DELT                                                    GS2M     724
      GO TO 180                                                         GS2M     725
  170 RHO=S(N)/DELT                                                     GS2M     726
  180 IF (LEAK.NE.CHK(9)) GO TO 200                                     GS2M     727
C                                                                       GS2M     728
C     ---COMPUTE NET LEAKAGE TERM FOR CONVERSION SIMULATION---          GS2M     729
      IF (RATE(N).EQ.0..OR.M(N).EQ.0.) GO TO 200                        GS2M     730
      HED1=AMAX1(STRT(N),TOP(N))                                        GS2M     731
      U=1.                                                              GS2M     732
      HED2=0.                                                           GS2M     733
      IF (PHE(N).GE.TOP(N)) GO TO 190                                   GS2M     734
      HED2=TOP(N)                                                       GS2M     735
      U=0.                                                              GS2M     736
  190 SL(N)=RATE(N)/M(N)*(RIVER(N)-HED1)+TL(N)*(HED1-HED2-STRT(N))      GS2M     737
  200 CONTINUE                                                          GS2M     738
C                                                                       GS2M     739
C     ---SIP 'NORMAL' ALGORITHM---                                      GS2M     740
C     ---FORWARD SUBSTITUTE, COMPUTING INTERMEDIATE VECTOR V---         GS2M     741
      E=-B-D-F-H-RHO-TL(N)*U-ETQB                                       GS2M     742
      CH=DEL(NA)*B/(1.+W*DEL(NA))                                       GS2M     743
      GH=ETA(NL)*D/(1.+W*ETA(NL))                                       GS2M     744
      BH=B-W*CH                                                         GS2M     745
      DH=D-W*GH                                                         GS2M     746
      EH=E+W*CH+W*GH                                                    GS2M     747
      FH=F-W*CH                                                         GS2M     748
      HH=H-W*GH                                                         GS2M     749
      ALFA=BH                                                           GS2M     750
      BETA=DH                                                           GS2M     751
      GAMA=EH-ALFA*ETA(NA)-BETA*DEL(NL)                                 GS2M     752
      DEL(N)=FH/GAMA                                                    GS2M     753
      ETA(N)=HH/GAMA                                                    GS2M     754
      RES=-D*PHI(NL)-F*PHI(NR)-H*PHI(NB)-B*PHI(NA)-E*PHI(N)-RHO*KEEP(N)- GS2M     755
     1SL(N)-QRE(N)-WELL(N)+ETQD-SUBS-TL(N)*STRT(N)                      GS2M     756
      V(N)=(HMAX*RES-ALFA*V(NA)-BETA*V(NL))/GAMA                        GS2M     757
  210 CONTINUE                                                          GS2M     758
C                                                                       GS2M     759
C     ---BACK SUBSTITUTE FOR VECTOR XI---                               GS2M     760
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```
      DO 220 I=1,I2
      I3=DIML-I
      DO 220 J=1,J2
      J3=DIMW-J
      N=I3+DIML*(J3-1)
      IF (T(N).EQ.0..OR.S(N).LT.0.) GO TO 220
      XI(N)=V(N)-DEL(N)*XI(N+DIML)-ETA(N)*XI(N+1)
C
C     ---COMPARE MAGNITUDE OF CHANGE WITH CLOSURE CRITERION---
      TCHK=ABS(XI(N))
      IF (TCHK.GT.BIGI) BIGI=TCHK
      PHI(N)=PHI(N)+XI(N)
  220 CONTINUE
      IF (BIGI.GT.ERR) TEST=1.
      TEST3(KOUNT+1)=BIGI
      IF (TEST.EQ.1.) GO TO 40
      RETURN
C
C     ..................................................................
C     ---ORDER EQUATIONS WITH THE LAST ROW FIRST - 3X3  EXAMPLE:
C             7 8 9
C             4 5 6
C             1 2 3
C     ..................................................................
  230 DO 340 II=1,I2
      I=DIML-II
      DO 340 J=2,JNO1
      N=I+DIML*(J-1)
      NL=N-DIML
      NR=N+DIML
      NA=N-1
      NB=N+1
C
C     ---SKIP COMPUTATIONS IF NODE IS OUTSIDE AQUIFER BOUNDARY---
      IF (T(N).EQ.0..OR.S(N).LT.0.) GO TO 340
C
C     ---COMPUTE COEFFICIENTS---
      D=TR(NL)/DELX(J)
      F=TR(N)/DELX(J)
      B=TC(NA)/DELY(I)
      H=TC(N)/DELY(I)
      IF (EVAP.NE.CHK(6)) GO TO 250
C
C     ---COMPUTE EXPLICIT AND IMPLICIT PARTS OF ET RATE---
      ETQB=0.
      ETQD=0.0
      IF (PHE(N).LE.GRND(N)-ETDIST) GO TO 250
      IF (PHE(N).GT.GRND(N)) GO TO 240
      ETQB=QET/ETDIST
      ETQD=ETQB*(ETDIST-GRND(N))
      GO TO 250
  240 ETQD=QET
C
C     ---COMPUTE STORAGE TERM---
  250 IF (CONVRT.EQ.CHK(7)) GO TO 260
      RHO=S(N)/DELT
      IF (WATER.EQ.CHK(2)) RHO=SY(N)/DELT
      GO TO 330
C
C     ---COMPUTE STORAGE COEFFICIENT FOR CONVERSION PROBLEM---
  260 SUBS=0.0
      IF (KEEP(N).GE.TOP(N).AND.PHE(N).GE.TOP(N)) GO TO 300
      IF (KEEP(N).LT.TOP(N).AND.PHE(N).LT.TOP(N)) GO TO 290
      IF (KEEP(N)-PHE(N)) 270,280,280
  270 SUBS=(SY(N)-S(N))/DELT*(KEEP(N)-TOP(N))
      GO TO 300
  280 SUBS=(S(N)-SY(N))/DELT*(KEEP(N)-TOP(N))                           GS2M
  290 RHO=SY(N)/DELT                                                    GS2M
      GO TO 310                                                         GS2M
  300 RHO=S(N)/DELT                                                     GS2M
  310 IF (LEAK.NE.CHK(9)) GO TO 330                                     GS2M
C                                                                       GS2M
C     ---COMPUTE NET LEAKAGE TERM FOR CONVERSION SIMULATION---          GS2M
      IF (RATE(N).EQ.0..OR.M(N).EQ.0.) GO TO 330                        GS2M
      HED1=AMAX1(STRT(N),TOP(N))                                        GS2M
      U=1.                                                              GS2M
      HED2=0.                                                           GS2M
      IF (PHE(N).GE.TOP(N)) GO TO 320                                   GS2M
      HED2=TOP(N)                                                       GS2M
      U=0.                                                              GS2M
  320 SL(N)=RATE(N)/M(N)*(RIVER(N)-HED1)+TL(N)*(HED1-HED2-STRT(N))      GS2M
  330 CONTINUE                                                          GS2M
C                                                                       GS2M
C     ---SIP 'REVERSE' ALGORITHM---                                     GS2M
C     ---FORWARD SUBSTITUTE, COMPUTING INTERMEDIATE VECTOR V---         GS2M
      E=-B-D-F-H-RHO-TL(N)*U-ETGB                                       GS2M
      CH=DEL(NB)*H/(1.+W*DEL(NB))                                       GS2M
      GH=ETA(NL)*D/(1.+W*ETA(NL))                                       GS2M
      BH=H-W*CH                                                         GS2M
      DH=D-W*GH                                                         GS2M
      EH=E+W*CH+W*GH                                                    GS2M
      FH=F-W*CH                                                         GS2M
      HH=B-W*GH                                                         GS2M
      ALFA=BH                                                           GS2M
      BETA=DH                                                           GS2M
      GAMA=EH-ALFA*ETA(NB)-BETA*DEL(NL)                                 GS2M
      DEL(N)=FH/GAMA                                                    GS2M
      ETA(N)=HH/GAMA                                                    GS2M
      RES=-D*PHI(NL)-F*PHI(NR)-H*PHI(NB)-B*PHI(NA)-E*PHI(N)-RHO*KEEP(N)-GS2M
     1SL(N)-QRE(N)-WELL(N)+ETGD-SUBS-TL(N)*STRT(N)                      GS2M
      V(N)=(HMAX*RES-ALFA*V(NB)-BETA*V(NL))/GAMA                        GS2M
  340 CONTINUE                                                          GS2M
C                                                                       GS2M
C     ---BACK SUBSTITUTE FOR VECTOR XI---                               GS2M
      DO 350 I3=2,INO1                                                  GS2M
      DO 350 J=1,J2                                                     GS2M
      J3=DIMW-J                                                         GS2M
      N=I3+DIML*(J3-1)                                                  GS2M
      IF (T(N).EQ.0..OR.S(N).LT.0.) GO TO 350                           GS2M
      XI(N)=V(N)-DEL(N)*XI(N+DIML)-ETA(N)*XI(N-1)                       GS2M
C                                                                       GS2M
C     ---COMPARE MAGNITUDE OF CHANGE WITH CLOSURE CRITERION---          GS2M
      TCHK=ABS(XI(N))                                                   GS2M
      IF (TCHK.GT.BIGI) BIGI=TCHK                                       GS2M
      PHI(N)=PHI(N)+XI(N)                                               GS2M
  350 CONTINUE                                                          GS2M
      IF (BIGI.GT.ERR) TEST=1.                                          GS2M
      TEST3(KOUNT+1)=BIGI                                               GS2M
      IF (TEST.EQ.1.) GO TO 40                                          GS2M
      RETURN                                                            GS2M
C                                                                       GS2M
C     ..................................................................GS2M
C                                                                       GS2M
C     ---FORMATS---                                                     GS2M
C                                                                       GS2M
C     ------------------------------------------------------------------GS2M
C                                                                       GS2M
C                                                                       GS2M
  360 FORMAT (*0EXCEEDED PERMITTED NUMBER OF ITERATIONS*/* *,39(1H*))   GS2M
  370 FORMAT (*-*,44X,*SOLUTION BY THE STRONGLY IMPLICIT PROCEDURE*/45X,GS2M
     143(*#*),//,61X,*BETA=*,F5.2)                                      GS2M
  380 FORMAT (1H0,I5,22H ITERATION PARAMETERS:,6E15.7/(/28X,6E15.7/))   GS2M
```

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      END                                                               GS2M     893
      SUBROUTINE SOLVE3(PHI,BE,G,TEMP,KEEP,PHE,STRT,T,S,QRE,WELL,TL,SL, GS2M     894
     1          DELX,      DELY,       XII,TEST3,TR,TC,GRND,SY,TOP,RATE,M GS2M     895
     2,RIVER,SURI,PERM,BOTTOM,DDN,WR,NWR)                               GS2M     896
C     ----------------------------------------------------------------- GS2M     897
C     SOLUTION BY THE ALTERNATING DIRECTION IMPLICIT PROCEDURE          GS2M     898
C     ----------------------------------------------------------------- GS2M     899
C                                                                       GS2M     900
C     SPECIFICATIONS:                                                   GS2M     901
      REAL   KEEP,M,IMK                                                 GS2M     902
      INTEGER R,P,PU,DIML,DIMW,CHK,WATER,CONVRT,EVAP,CHCK,PNCH,NUM,HEAD, GS2M     903
     1CONTR,LEAK,RECH,SIP,ADI                                           GS2M     904
C                                                                       GS2M     905
      DIMENSION PHI(1), BE(1), G(1), TEMP(1), KEEP(1), PHE(1), STRT(1), GS2M     906
     1T(1),S(1),QRE(1),WELL(1),TL(1),SL(1),                             GS2M     907
     2DELX(1),DELY(1),XII(1),TEST3(1),TR(1),                            GS2M     908
     3 TC(1), GRND(1), SY(1), TOP(1), RATE(1), M(1), RIVER(1)           GS2M     909
     4 ,SURI(1),PERM(1),BOTTOM(1),DDN(1),WR(1),NWR(1),RHOP(20)          GS2M     910
C                                                                       GS2M     911
      COMMON /SARRAY/ VF4(11),CHK(15),IH                                GS2M     912
      COMMON /SPARAM/ WATER,CONVRT,EVAP,CHCK,PNCH,NUM,HEAD,CONTR,EROR,LE GS2M     913
     1AK,RECH,SIP,U,SS,TT,TMIN,ETDIST,QET,ERR,TMAX,CDLT,HMAX,YDIM,WIDTH, GS2M     914
     2NUMS,LSOR,ADI,DELT,SUM,SUMP,SUBS,STORE,TEST,ETQB,ETQD,FACTX,FACTY, GS2M     915
     3IERR,KOUNT,IFINAL,NUMT,KT,KP,NPER,KTH,ITMAX,LENGTH,NWEL,NW,DIML,DI GS2M     916
     4MW,JNO1,INO1,R,P,PU,I,J,IDK1,IDK2,LKPR                            LKPR      10
C     ................................................................. GS2M     918
C                                                                       GS2M     919
C     ---COMPUTE AND PRINT ITERATION PARAMETERS---                      GS2M     920
C     ********************                                              GS2M     921
      ENTRY ITER3                                                       GS2M     922
C     ********************                                              GS2M     923
      HMIN=2.                                                           GS2M     924
      IN4=DIMW-2                                                        GS2M     925
      IN5=DIML-2                                                        GS2M     926
      XVAL=3.1415**2/(2.*IN4*IN4)                                       GS2M     927
      YVAL=3.1415**2/(2.*IN5*IN5)                                       GS2M     928
      DO 10 I=2,INO1                                                    GS2M     929
      DO 10 J=2,JNO1                                                    GS2M     930
      N=I+DIML*(J-1)                                                    GS2M     931
      IF (T(N).EQ.0.) GO TO 10                                          GS2M     932
      XPART=XVAL*(1/(1+DELX(J)**2*FACTY/DELY(I)**2*FACTX))              GS2M     933
      YPART=YVAL*(1/(1+DELY(I)**2*FACTX/DELX(J)**2*FACTY))              GS2M     934
      HMIN=AMIN1(HMIN,XPART,YPART)                                      GS2M     935
   10 CONTINUE .                                                        GS2M     936
      ALPHA=EXP(ALOG(HMAX/HMIN)/(LENGTH-1))                             GS2M     937
      RHOP(1)=HMIN                                                      GS2M     938
      DO 20 NTIME=2,LENGTH                                              GS2M     939
   20 RHOP(NTIME)=RHOP(NTIME-1)*ALPHA                                   GS2M     940
      WRITE (P,400)                                                     GS2M     941
      WRITE (P,410) LENGTH,(RHOP(J),J=1,LENGTH)                         GS2M     942
      BE(1)=0.                                                          GS2M     943
      G(1)=0.                                                           GS2M     944
      RETURN                                                            GS2M     945
C     ................................................................. GS2M     946
C                                                                       GS2M     947
C     ---INITIALIZE DATA FOR A NEW ITERATION---                         GS2M     948
   30 KOUNT=KOUNT+1                                                     GS2M     949
      IF (KOUNT.LE.ITMAX) GO TO 40                                      GS2M     950
      WRITE (P,390)                                                     GS2M     951
      CALL TERM1(PHI,KEEP,STRT,SURI,T,TR,TC,S,QRE,WELL,TL,PERM,BOTTOM,  GS2M     952
     1SY,RATE,RIVER,M,TOP,GRND,DELX,DDN,DELY,WR,NWR,TEST3)              GS2M     953
   40 IF (MOD(KOUNT,LENGTH)) 50,50,60                                   GS2M     954
C     ************************                                          GS2M     955
      ENTRY NEWITC                                                      GS2M     956
C     ************************                                          GS2M     957
   50 NTH=0                                                             GS2M     958
   60 NTH=NTH+1
      PARAM=RHOP(NTH)
      TEST3(KOUNT+1)=0.
      TEST=0.
      N=DIML*DIMW
      DO 70 I=1,N
   70 PHE(I)=PHI(I)
      BIGI=0.0
C
C     ---COMPUTE TRANSMISSIVITY AND T COEFFICIENTS IN WATER TABLE
C     OR WATER TABLE-ARTESIAN SIMUATION---
      IF (WATER.NE.CHK(2)) GO TO 80
      CALL TRANS(PHI,KEEP,STRT,SURI,T,TR,TC,S,QRE,WELL,TL,SL,
     1PERM,BOTTOM,SY,RATE,RIVER,M,TOP,GRND,DELX,DDN,DELY,WR,NWR,TEST3)
C     ...................................................................
C     ...........................................................................
C     ---SOLUTION BY ADI---
C     ---------------------
C     ---COMPUTE IMPLICITLY ALONG ROWS---
   80 NO3=DIMW-2
      DO 90 J=1,DIMW
      N=1+DIML*(J-1)
   90 TEMP(J)=PHI(N)
      DO 230 I=2,DIML
      DO 200 J=2,JNO1
      N=I+DIML*(J-1)
      NA=N-1
      NB=N+1
      NL=N-DIML
      NR=N+DIML
      BE(J)=0.0
      G(J)=0.0
C
C     ---SKIP COMPUTATIONS IF NODE IS OUTSIDE AQUIFER BOUNDARY---
      IF (T(N).EQ.0..OR.S(N).LT.0.) GO TO 200
C
C     ---COMPUTE COEFFICIENTS---
      D=TR(N-DIML)/DELX(J)
      F=TR(N)/DELX(J)
      B=TC(N-1)/DELY(I)
      H=TC(N)/DELY(I)
      IF (EVAP.NE.CHK(6)) GO TO 110
C
C     ---COMPUTE EXPLICIT AND IMPLICIT PARTS OF ET RATE---
      ETQB=0.
      ETQD=0.0
      IF (PHE(N).LE.GRND(N)-ETDIST) GO TO 110
      IF (PHE(N).GT.GRND(N)) GO TO 100
      ETQB=QET/ETDIST
      ETQD=ETQB*(ETDIST-GRND(N))
      GO TO 110
  100 ETQD=QET
C
C     ---COMPUTE STORAGE TERM---
  110 IF (CONVRT.EQ.CHK(7)) GO TO 120
      RHO=S(N)/DELT
      IF (WATER.EQ.CHK(2)) RHO=SY(N)/DELT
      GO TO 190
C
C     ---COMPUTE STORAGE COEFFICIENT FOR CONVERSION PROBLEM---
  120 SUBS=0.0
      IF (KEEP(N).GE.TOP(N).AND.PHE(N).GE.TOP(N)) GO TO 160
      IF (KEEP(N).LT.TOP(N).AND.PHE(N).LT.TOP(N)) GO TO 150
      IF (KEEP(N)-PHE(N)) 130,140,140
  130 SUBS=(SY(N)-S(N))/DELT*(KEEP(N)-TOP(N))
      GO TO 160
  140 SUBS=(S(N)-SY(N))/DELT*(KEEP(N)-TOP(N))                           GS2M     1025
  150 RHO=SY(N)/DELT                                                    GS2M     1026
      GO TO 170                                                         GS2M     1027
  160 RHO=S(N)/DELT                                                     GS2M     1028
  170 IF (LEAK.NE.CHK(9)) GO TO 190                                     GS2M     1029
C                                                                       GS2M     1030
C     ---COMPUTE NET LEAKAGE TERM FOR CONVERSION SIMULATION---          GS2M     1031
      IF (RATE(N).EQ.0..OR.M(N).EQ.0.) GO TO 190                        GS2M     1032
      HED1=AMAX1(STRT(N),TOP(N))                                        GS2M     1033
      U=1.                                                              GS2M     1034
      HED2=0.                                                           GS2M     1035
      IF (PHE(N).GE.TOP(N)) GO TO 180                                   GS2M     1036
      HED2=TOP(N)                                                       GS2M     1037
      U=0.                                                              GS2M     1038
  180 SL(N)=RATE(N)/M(N)*(RIVER(N)-HED1)+TL(N)*(HED1-HED2-STRT(N))      GS2M     1039
  190 CONTINUE                                                          GS2M     1040
C                                                                       GS2M     1041
C     ---CALCULATE VALUES FOR PARAMETERS USED IN THOMAS ALGORITHM       GS2M     1042
C     AND FORWARD SUBSTITUTE TO COMPUTE INTERMEDIATE VECTOR G---        GS2M     1043
      IMK=(B+D+F+H)*PARAM                                               GS2M     1044
      E=-D-F-RHO-IMK-TL(N)*U-ETQB                                       GS2M     1045
      W=E-D*BE(J-1)                                                     GS2M     1046
      BE(J)=F/W                                                         GS2M     1047
      Q=-B*PHI(NA)+(B+H-IMK-E)*PHI(N)-H*PHI(NB)-RHO*KEEP(N)-SL(N)-QRE(N) GS2M     1048
     1-WELL(N)+ETQD-SUBS-TL(N)*STRT(N)-D*PHI(NL)-F*PHI(NR)              GS2M     1049
      G(J)=(Q-D*G(J-1))/W                                               GS2M     1050
  200 CONTINUE                                                          GS2M     1051
C                                                                       GS2M     1052
C     ---BACK SUBSTITUTE FOR HEAD VALUES AND PLACE THEM IN TEMP---      GS2M     1053
      XII(DIMW)=0.D0                                                    GS2M     1054
      DO 220 KNO4=1,NO3                                                 GS2M     1055
      NO4=DIMW-KNO4                                                     GS2M     1056
      N=I+DIML*(NO4-1)                                                  GS2M     1057
C                                                                       GS2M     1058
C     ---FIRST PLACE TEMP VALUES IN PHI(N-1)---                         GS2M     1059
      PHI(N-1)=TEMP(NO4)                                                GS2M     1060
      IF (T(N).NE.0..AND.S(N).GE.0.) GO TO 210                          GS2M     1061
      XII(NO4)=0.D0                                                     GS2M     1062
      GO TO 220                                                         GS2M     1063
  210 XII(NO4)=G(NO4)-BE(NO4)*XII(NO4+1)                                GS2M     1064
  220 TEMP(NO4)=PHI(N)+XII(NO4)                                         GS2M     1065
  230 CONTINUE                                                          GS2M     1066
C     ................................................................. GS2M     1067
C                                                                       GS2M     1068
C     ---COMPUTE IMPLICITLY ALONG COLUMNS---                            GS2M     1069
      NO3=DIML-2                                                        GS2M     1070
      DO 240 I=1,DIML                                                   GS2M     1071
  240 TEMP(I)=PHI(I)                                                    GS2M     1072
      DO 380 J=2,DIMW                                                   GS2M     1073
      DO 350 I=2,INO1                                                   GS2M     1074
      N=I+DIML*(J-1)                                                    GS2M     1075
      NA=N-1                                                            GS2M     1076
      NB=N+1                                                            GS2M     1077
      NL=N-DIML                                                         GS2M     1078
      NR=N+DIML                                                         GS2M     1079
      BE(I)=0.0                                                         GS2M     1080
      G(I)=0.0                                                          GS2M     1081
C                                                                       GS2M     1082
C     ---SKIP COMPUTATIONS IF NODE IS OUTSIDE AQUIFER BOUNDARY---       GS2M     1083
      IF (T(N).EQ.0..OR.S(N).LT.0.) GO TO 350                           GS2M     1084
C                                                                       GS2M     1085
C     ---COMPUTE COEFFICIENTS---                                        GS2M     1086
      D=TR(N-DIML)/DELX(J)                                              GS2M     1087
      F=TR(N)/DELX(J)                                                   GS2M     1088
      B=TC(N-1)/DELY(I)                                                 GS2M     1089
      H=TC(N)/DELY(I)                                                   GS2M     1090
      IF (EVAP.NE.CHK(6)) GO TO 260
C
C     ---COMPUTE EXPLICIT AND IMPLICIT PARTS OF ET RATE---
      ETQB=0.
      ETQD=0.0
      IF (PHE(N).LE.GRND(N)-ETDIST) GO TO 260
      IF (PHE(N).GT.GRND(N)) GO TO 250
      ETQB=QET/ETDIST
      ETQD=ETQB*(ETDIST-GRND(N))
      GO TO 260
  250 ETQD=QET
C
C     ---COMPUTE STORAGE TERM---
  260 IF (CONVRT.EQ.CHK(7)) GO TO 270
      RHO=S(N)/DELT
      IF (WATER.EQ.CHK(2)) RHO=SY(N)/DELT
      GO TO 340
C
C     ---COMPUTE STORAGE COEFFICIENT FOR CONVERSION PROBLEM---
  270 SUBS=0.0
      IF (KEEP(N).GE.TOP(N).AND.PHE(N).GE.TOP(N)) GO TO 310
      IF (KEEP(N).LT.TOP(N).AND.PHE(N).LT.TOP(N)) GO TO 300
      IF (KEEP(N)-PHE(N)) 280,290,290
  280 SUBS=(SY(N)-S(N))/DELT*(KEEP(N)-TOP(N))
      GO TO 310
  290 SUBS=(S(N)-SY(N))/DELT*(KEEP(N)-TOP(N))
  300 RHO=SY(N)/DELT
      GO TO 320
  310 RHO=S(N)/DELT
  320 IF (LEAK.NE.CHK(9)) GO TO 340
C
C     ---COMPUTE NET LEAKAGE TERM FOR CONVERSION SIMULATION---
      IF (RATE(N).EQ.0..OR.M(N).EQ.0.) GO TO 340
      HED1=AMAX1(STRT(N),TOP(N))
      U=1.
      HED2=0.
      IF (PHE(N).GE.TOP(N)) GO TO 330
      HED2=TOP(N)
      U=0.
  330 SL(N)=RATE(N)/M(N)*(RIVER(N)-HED1)+TL(N)*(HED1-HED2-STRT(N))
  340 CONTINUE
C
C     ---CALCULATE VALUES FOR PARAMETERS USED IN THOMAS ALGORITHM
C     AND FORWARD SUBSTITUTE TO COMPUTE INTERMEDIATE VECTOR G---
      IMK=(B+D+F+H)*PARAM
      E=-B-H-RHO-IMK-TL(N)*U-ETQB
      W=E-B*BE(I-1)
      BE(I)=H/W
      Q=-D*PHI(NL)+(D+F-IMK-E)*PHI(N)-F*PHI(NR)-RHO*KEEP(N)-SL(N)-QRE(N)
     1-WELL(N)+ETQD-SUBS-TL(N)*STRT(N)-B*PHI(NA)-H*PHI(NB)
      G(I)=(Q-B*G(I-1))/W
  350 CONTINUE
C
C     ---BACK SUBSTITUTE FOR HEAD VALUES AND PLACE THEM IN TEMP---
      XII(DIML)=0.D0
      DO 370 KNO4=1,NO3
      NO4=DIML-KNO4
      N=NO4+DIML*(J-1)
C
C     ---FIRST PLACE TEMP VALUES IN PHI(N-DIML)----
      PHI(N-DIML)=TEMP(NO4)
      IF (T(N).NE.0..AND.S(N).GE.0.) GO TO 360
      XII(NO4)=0.D0
      TEMP(NO4)=PHI(N)
      GO TO 370
  360 XII(NO4)=G(NO4)-BE(NO4)*XII(NO4+1)
```

```
      TEMP(NO4)=PHI(N)+XII(NO4)                                          GS2M    1157
C                                                                        GS2M    1158
C     ---COMPARE MAGNITUDE OF CHANGE WITH CLOSURE CRITERION---           GS2M    1159
      TCHK=ABS(TEMP(NO4)-PHE(N))                                         GS2M    1160
      IF (TCHK.GT.BIGI) BIGI=TCHK                                        GS2M    1161
  370 CONTINUE                                                           GS2M    1162
  380 CONTINUE                                                           GS2M    1163
      IF (BIGI.GT.ERR) TEST=1.                                           GS2M    1164
      TEST3(KOUNT+1)=BIGI                                                GS2M    1165
      IF (TEST.EQ.1.) GO TO 30                                           GS2M    1166
      RETURN                                                             GS2M    1167
C     .................................................................. GS2M    1168
C                                                                        GS2M    1169
C     ---FORMATS---                                                      GS2M    1170
C                                                                        GS2M    1171
C     ------------------------------------------------------------------ GS2M    1172
C                                                                        GS2M    1173
C                                                                        GS2M    1174
  390 FORMAT (*0EXCEEDED PERMITTED NUMBER OF ITERATIONS*/* *,39(1H*))    GS2M    1175
  400 FORMAT (*-*,38X,*SOLUTION BY THE ALTERNATING DIRECTION IMPLICIT PR GS2M    1176
     1OCEDURE*/39X,56(*=*))                                              GS2M    1177
  410 FORMAT (///1H0,I5,22H ITERATION PARAMETERS:,8E12.3//28X, 8E12.3)   GS2M    1178
      END                                                                GS2M    1179
      SUBROUTINE SOLVE2(PHI,D1,D2,D3,KEEP,PHE,STRT,T,S,QRE,WELL,TL,      GS2M    1180
     1 SL,            DELX,D8,DELY,D9,TEST3,TR,TC,GRND,SY,TOP,RATE,M,    GS2M    1181
     2 RIVER,SURI,PERM,BOTTOM,DDN,WR,NWR)                                GS2M    1182
C     SPECIFICATIONS:                                                    GS2M    1183
      REAL   KEEP,M,KEEPN                                                GS2M    1184
      INTEGER R,P,PU,DIML,DIMW,CHK,WATER,CONVRT,EVAP,CHCK,PNCH,NUM,HEAD, GS2M    1185
     1CONTR,LEAK,RECH,SIP,ADI                                            GS2M    1186
C                                                                        GS2M    1187
      DIMENSION PHI(1),                       KEEP(1), PHE(1), STRT(1),  GS2M    1188
     1T(1), S(1), QRE(1), WELL(1), TL(1), SL(1),                         GS2M    1189
     2      DELX(1),          DELY(1),          TEST3(1), TR(1), TC(1),  GS2M    1190
     3GRND(1), SY(1), TOP(1), RATE(1), M(1), RIVER(1),                   GS2M    1191
     4SURI(1),PERM(1),BOTTOM(1),DDN(1),WR(1),NWR(1)                      GS2M    1192
      DIMENSION AU(500,5), AL(500,31), IC(500,5), IN(50,50), B(1000)     GS2M    1193
C                                                                        GS2M    1194
      COMMON /SARRAY/ VF4(11),CHK(15),IH                                 GS2M    1195
      COMMON /SPARAM/ WATER,CONVRT,EVAP,CHCK,PNCH,NUM,HEAD,CONTR,EROR,LE GS2M    1196
     1AK,RECH,SIP,U,SS,TT,TMIN,ETDIST,QET,ERR,TMAX,CDLT,HMAX,YDIM,WIDTH, GS2M    1197
     2NUMS,LSOR,ADI,DELT,SUM,SUMP,SUBS,STORE,TEST,ETQB,ETQD,FACTX,FACTY, GS2M    1198
     3IERR,KOUNT,IFINAL,NUMT,KT,KP,NPER,KTH,ITMAX,LENGTH,NWEL,NW,DIML,DI GS2M    1199
     4MW,JNO1,INO1,R,P,PU,IXX,JXX,IDK1,IDK2,LKPR                         LKPR      11
      RETURN                                                             GS2M    1201
C     .................................................................. GS2M    1202
C                                                                        GS2M    1203
C********************                                                   GS2M    1204
      ENTRY ITER2                                                        GS2M    1205
C********************                                                   GS2M    1206
      READ 530, THETA                                                    GS2M    1207
      IM=DIML-2                                                          GS2M    1208
      JM=DIMW-2                                                          GS2M    1209
C*****COMPUTE EQUATION NUMBERS FOR D4 ORDERING                           GS2M    1210
      NXP=IM+JM-1                                                        GS2M    1211
      DO 10 I=1,IM                                                       GS2M    1212
      DO 10 J=1,JM                                                       GS2M    1213
      N=I+J*DIML+1                                                       GS2M    1214
      PHE(N)=STRT(N)                                                     GS2M    1215
   10 IN(I,J)=0                                                          GS2M    1216
      K=0                                                                GS2M    1217
C*****ORDER--LEFT TO RIGHT, BOTTOM TO TOP                                GS2M    1218
      DO 20 I=1,NXP,2                                                    GS2M    1219
      DO 20 J=1,JM                                                       GS2M    1220
      IK=I-J+1                                                           GS2M    1221
      IF (IK.LT.1) GO TO 20                                              GS2M    1222
      IF (IK.GT.IM) GO TO 20
      N=IK+J*DIML+1
      IF(T(N).LE.0..OR.S(N).LT.0.) GO TO 20
      K=K+1
      IN(IK,J)=K
   20 CONTINUE
      ICR=K+1
      DO 30 I=2,NXP,2
      DO 30 J=1,JM
      IK=I-J+1
      IF (IK.LT.1) GO TO 30
      IF (IK.GT.IM) GO TO 30
      N=IK+J*DIML+1
      IF(T(N).LE.0..OR.S(N).LT.0.) GO TO 30
      K=K+1
      IN(IK,J)=K
   30 CONTINUE
C*****COMPUTE BANDWIDTH AND DETERMINE CONNECTING EQUATION NUMBERS
      MNO=9999
      MXO=0
      DO 80 I=1,IM
      DO 80 J=1,JM
      IR=IN(I,J)
      IF (IR.EQ.0.OR.IR.GE.ICR) GO TO 80
      JU=1
C**   LEFT
      IF ((J-1).LT.1) GO TO 40
      IF (IN(I,J-1).EQ.0) GO TO 40
      JU=JU+1
      IC(IR,JU)=IN(I,J-1)
      MM=IN(I,J-1)-IR
      MXO=MAX0(MM,MXO)
      MNO=MIN0(MM,MNO)
C**   ABOVE
   40 IF ((I-1).LT.1) GO TO 50
      IF (IN(I-1,J).EQ.0) GO TO 50
      JU=JU+1
      IC(IR,JU)=IN(I-1,J)
      MM=IN(I-1,J)-IR
      MNO=MIN0(MM,MNO)
      MXO=MAX0(MM,MXO)
C**   BELOW
   50 IF ((I+1).GT.IM) GO TO 60
      IF (IN(I+1,J).EQ.0) GO TO 60
      JU=JU+1
      IC(IR,JU)=IN(I+1,J)
      MM=IN(I+1,J)-IR
      MXO=MAX0(MM,MXO)
      MNO=MIN0(MM,MNO)
C**   RIGHT
   60 IF ((J+1).GT.JM) GO TO 70
      IF (IN(I,J+1).EQ.0) GO TO 70
      JU=JU+1
      IC(IR,JU)=IN(I,J+1)
      MM=IN(I,J+1)-IR
      MXO=MAX0(MM,MXO)
      MNO=MIN0(MM,MNO)
   70 IC(IR,1)=JU
   80 CONTINUE
      IB=MXO-MNO+2
      NEQ=K
      ICR1=ICR-1
      IB1=IB-1
      LH1=NEQ-ICR1
      LH=NEQ-ICR
      WRITE (P,510) HMAX,LENGTH,ITMAX,THETA
      WRITE (P,520) ICR1,LH1,IB1,ICR1,NEQ,IM,JM
      RETURN
C********************
      ENTRY NEWITB
C********************
      KOUNT=0
      ITYPE=0
      IF (CDLT.EQ.1..AND.KT.GT.1.AND.LENGTH.EQ.0.AND.EVAP.NE.CHK(6)) ITY
     1PE=1
      IF (WATER.NE.CHK(2)) GO TO 100
      ITYPE=2
      DO 90 I=1,IM
      DO 90 J=1,JM
      N=I+J*DIML+1
      IF (T(N).LE.0..OR.S(N).LT.0.) GO TO 90
      DELTAH=(PHI(N)-PHE(N))*CDLT*THETA
      DELMAX=0.1*(PHI(N)-BOTTOM(N))
      IF (ABS(DELTAH).GT.DELMAX) DELTAH=DELTAH*DELMAX/ABS(DELTAH)
      PHI(N)=PHI(N)+DELTAH
   90 CONTINUE
      CALL TRANS
     1(PHI,KEEP,STRT,SURI,T,TR,TC,S,QRE,WELL,TL,SL,
     2PERM,BOTTOM,SY,RATE,RIVER,M,TOP,GRND,DELX,DDN,DELY,WR,NWR,TEST3)
  100 BIGI=0.
C** LOAD MATRIX A AND VECTOR B FOR D4
      IF (ITYPE.EQ.1) GO TO 130
      DO 110 I=1,ICR1
      DO 110 J=1,S
  110 AU(I,J)=0.
      DO 120 I=1,LH1
      DO 120 J=1,IB1
  120 AL(I,J)=0.
  130 DO 140 I=1,NEQ
  140 B(I)=0.
      DO 310 I=1,IM
      DO 310 J=1,JM
      IF (IN(I,J).EQ.0) GO TO 310
      IR=IN(I,J)
      N=I+1+DIML*J
      NA=N-1
      NB=N+1
      NL=N-DIML
      NR=N+DIML
      DXB=DELX(J+1)
      DYB=DELY(I+1)
      STRTN=STRT(N)
      KEEPN=KEEP(N)
      PHEN=PHI(N)
      IF (ITYPE.EQ.1) PHEN=PHE(N)
C     ..................................................................
C
C     ---COMPUTE COEFFICIENTS---
      IF (EVAP.NE.CHK(6)) GO TO 160
C
C     ---COMPUTE EXPLICIT AND IMPLICIT PARTS OF ET RATE---
      GRNDN=GRND(N)
      ETQB=0.
      ETQD=0.0
      IF (PHEN.LE.GRNDN-ETDIST) GO TO 160
      IF (PHEN.GT.GRNDN) GO TO 150
      ETQB=QET/ETDIST
      ETQD=ETQB*(ETDIST-GRNDN)
      GO TO 160
  150 ETQD=QET
C
C     ---COMPUTE STORAGE TERM---
```

```
  160 IF (CONVRT.EQ.CHK(7)) GO TO 170
      RHO=S(N)/DELT
      IF (WATER.EQ.CHK(2)) RHO=SY(N)/DELT
      GO TO 240
C
C     ---COMPUTE STORAGE COEFFICIENT FOR CONVERSION PROBLEM---
  170 SUBS=0.0
      TOPN=TOP(N)
      IF (KEEPN.GE.TOPN.AND.PHEN.GE.TOPN) GO TO 210
      IF (KEEPN.LT.TOPN.AND.PHEN.LT.TOPN) GO TO 200
      IF (KEEPN-PHEN) 180,190,190
  180 SUBS=(SY(N)-S(N))/DELT*(KEEPN-TOPN)
      GO TO 210
  190 SUBS=(S(N)-SY(N))/DELT*(KEEPN-TOPN)
  200 RHO=SY(N)/DELT
      GO TO 220
  210 RHO=S(N)/DELT
  220 IF (LEAK.NE.CHK(9)) GO TO 240
C
C     ---COMPUTE NET LEAKAGE TERM FOR CONVERSION SIMULATION---
      IF (RATE(N).EQ.0..OR.M(N).EQ.0.) GO TO 240
      HED1=AMAX1(STRTN,TOPN)
      U=1.
      HED2=0.
      IF (PHEN.GE.TOPN) GO TO 230
      HED2=TOPN
      U=0.
  230 SL(N)=RATE(N)/M(N)*(RIVER(N)-HED1)+TL(N)*(HED1-HED2-STRTN)
  240 CONTINUE
C
      AREA=DXB*DYB
      E=(RHO+TL(N)*U+ETQB)*AREA
C*****LOAD COEFFICIENTS INTO AU AND AL
      CL=(TR(NL))*DYB
      CR=(TR(N))*DYB
      CA=(TC(NA))*DXB
      CB=(TC(N))*DXB
      IF (ITYPE.EQ.1) GO TO 300
      IF (IR.GE.ICR) GO TO 290
      JU=1
      IF ((J-1).LT.1) GO TO 250
      IF (IN(I,J-1).EQ.0) GO TO 250
      JU=JU+1
      AU(IR,JU)=-CL
  250 IF ((I-1).LT.1) GO TO 260
      IF (IN(I-1,J).EQ.0) GO TO 260
      JU=JU+1
      AU(IR,JU)=-CA
  260 IF ((I+1).GT.IM) GO TO 270
      IF (IN(I+1,J).EQ.0) GO TO 270
      JU=JU+1
      AU(IR,JU)=-CB
  270 IF ((J+1).GT.JM) GO TO 280
      IF (IN(I,J+1).EQ.0) GO TO 280
      JU=JU+1
      AU(IR,JU)=-CR
  280 E=E+CA+CB+CL+CR
      AU(IR,1)=E
      B(IR)=(RHO*KEEPN+SL(N)+QRE(N)+WELL(N)-ETQD+SUBS+TL(N)*STRTN)*AREA+
     1CA*PHI(NA)+CB*PHI(NB)+CL*PHI(NL)+CR*PHI(NR)-E*PHI(N)
      IF(T(N).GT.0.) GO TO 310
      AU(IR,1)=1.
      B(IR)=0.
      GO TO 310
  290 IRR=IR-ICR1
      E=E+CA+CB+CL+CR
      AL(IRR,1)=E
      B(IR)=(RHO*KEEPN+SL(N)+QRE(N)+WELL(N)-ETQD+SUBS+TL(N)*STRTN)*AREA+
     1CA*PHI(NA)+CB*PHI(NB)+CL*PHI(NL)+CR*PHI(NR)-E*PHI(N)
      IF(T(N).GT.0.) GO TO 310
      AL(IRR,1)=1.
      B(IR)=0.
      GO TO 310
  300 B(IR)=(RHO*KEEPN+SL(N)+QRE(N)+WELL(N)-ETQD+SUBS+TL(N)*STRTN)*AREA+
     1CA*PHI(NA)+CB*PHI(NB)+CL*PHI(NL)+CR*PHI(NR)-(E+CR+CL+CA+CB)*PHI(N)
      IF(T(N).GT.0.) GO TO 310
      B(IR)=0.
  310 CONTINUE
      IF (ITYPE.EQ.1) GO TO 380
C*****ELIMINATE TO FILL AL
      DO 340 I=1,ICR1
      JJ=IC(I,1)
      C1=1./AU(I,1)
      DO 330 J=2,JJ
      LR=IC(I,J)
      L=LR-ICR1
      C=AU(I,J)*C1
      DO 320 K=J,JJ
      KL=IC(I,K)-LR+1
      AL(L,KL)=AL(L,KL)-C*AU(I,K)
  320 CONTINUE
      AU(I,J)=C
  330 CONTINUE
  340 CONTINUE
C*****ELIMINATE AL
      DO 370 I=1,LH
      IR=I+ICR1
      L=I
      C1=1./AL(I,1)
      DO 360 J=2,IB1
      L=L+1
      IF (AL(I,J).EQ.0.) GO TO 360
      C=AL(I,J)*C1
      KL=0
      DO 350 K=J,IB1
      KL=KL+1
      IF (AL(I,K).NE.0.) AL(L,KL)=AL(L,KL)-C*AL(I,K)
  350 CONTINUE
      AL(I,J)=C
  360 CONTINUE
  370 CONTINUE
C**MODIFY RHS, UPPER HALF
  380 DO 400 I=1,ICR1
      JJ=IC(I,1)
      DO 390 J=2,JJ
      LR=IC(I,J)
      B(LR)=B(LR)-AU(I,J)*B(I)
  390 CONTINUE
  400 B(I)=B(I)/AU(I,1)
C**MODIFY RHS, LOWER HALF
      DO 420 I=1,LH
      IR=I+ICR1
      LR=IR
      DO 410 J=2,IB1
      LR=LR+1
      IF (AL(I,J).NE.0.) B(LR)=B(LR)-AL(I,J)*B(IR)
  410 CONTINUE
  420 B(IR)=B(IR)/AL(I,1)
C*****BACK SOLVE--LOWER HALF
      B(NEQ)=B(NEQ)/AL(NEQ-ICR1,1)
      DO 440 I=1,LH
      K=NEQ-I
      KL=K-ICR1
      L=K
      DO 430 J=2,IB1
      L=L+1
      IF (AL(KL,J).NE.0.) B(K)=B(K)-AL(KL,J)*B(L)
  430 CONTINUE
  440 CONTINUE
C*****BACK SOLVE--UPPER HALF
      DO 460 I=1,ICR1
      K=ICR-I
      JJ=IC(K,1)
      DO 450 J=2,JJ
      L=IC(K,J)
      B(K)=B(K)-AU(K,J)*B(L)
  450 CONTINUE
  460 CONTINUE
C*****COMPUTE NEW PHI VALUES
      DO 470 I=1,IM
      DO 470 J=1,JM
      IF (IN(I,J).EQ.0) GO TO 470
      N=I+1+DIML*J
      IF (ITYPE.NE.1) PHE(N)=KEEP(N)
      L=IN(I,J)
      TCHK=ABS(B(L))
      IF (TCHK.GT.BIGI) BIGI=TCHK
      PHI(N)=PHI(N)+HMAX*B(L)
  470 CONTINUE
C*****CHECK TERMINATION CONDITIONS
      TEST3(KOUNT+1)=BIGI
      IF (LENGTH.GT.0.AND.WATER.NE.CHK(2)) GO TO 490
      IF (WATER.NE.CHK(2)) RETURN
      IF (KOUNT.GE.LENGTH.AND.BIGI.LE.ERR) RETURN
      KOUNT=KOUNT+1
      IF (KOUNT.LE.ITMAX) GO TO 480
      WRITE (P,500)
      CALL TRANS
     1(PHI,KEEP,STRT,SURI,T,TR,TC,S,QRE,WELL,TL,SL,
     2PERM,BOTTOM,SY,RATE,RIVER,M,TOP,GRND,DELX,DDN,DELY,WR,NWR,TEST3)
      CALL TERM1
     1(PHI,KEEP,STRT,SURI,T,TR,TC,S,QRE,WELL,TL,PERM,
     2BOTTOM,SY,RATE,RIVER,M,TOP,GRND,DELX,DDN,DELY,WR,NWR,TEST3)
      RETURN
  480 CALL TRANS
     1(PHI,KEEP,STRT,SURI,T,TR,TC,S,QRE,WELL,TL,SL,
     2PERM,BOTTOM,SY,RATE,RIVER,M,TOP,GRND,DELX,DDN,DELY,WR,NWR,TEST3)
      GO TO 100
  490 IF (KOUNT.GE.LENGTH.AND.BIGI.LE.ERR) RETURN
      KOUNT=KOUNT+1
      IF (KOUNT.LE.ITMAX) GO TO 100
      WRITE (P,500)
      CALL TERM1
     1(PHI,KEEP,STRT,SURI,T,TR,TC,S,QRE,WELL,TL,PERM,
     2BOTTOM,SY,RATE,RIVER,M,TOP,GRND,DELX,DDN,DELY,WR,NWR,TEST3)
      RETURN
C
C
  500 FORMAT (*0EXCEEDED PERMITTED NUMBER OF ITERATIONS FOR NON-LINEAR S
     1OLUTION*/* *,63(*I*))
  510 FORMAT (1H-,41X,*SOLUTION BY LDU FACTORIZATION ASSUMING D4 ORDERIN
     1G*,/,42X,50(1H*),//,61X,*BETA =*,F5.2,//,45X,*ITERATIONS:  MINIMUM
     2 =*,I5,/,58X,*MAXIMUM =*,I5,/,60X,*THETA =*,F5.2)
  520 FORMAT (1H-,25X,*IIIIIWARNINGIIIIIMINIMUM DIMENSIONS FOR ARRAYS US
     1ED BY THIS METHOD ARE AS FOLLOWS:*,//,64X,*AU:*,I5,* BY    5*,/,64
     2X,*AL:*,I5,* BY*,I5,/,64X,*IC:*,I5,* BY    5*,/,65X,*B:*,I5,
     3/,64X,*IN:*,I5,* BY*,I5)
  530 FORMAT (8F10.4)
```

```
      END
      SUBROUTINE STEP(PHI,KEEP,STRT,SURI,T,TR,TC,S,QRE,WELL,TL,PERM,    GS2M      1553
     1 BOTTOM,SY,RATE,RIVER,M,TOP,GRND,DELX,DDN,DELY,WR,NWR,TEST3)      GS2M      1554
C     ------------------------------------------------------------      GS2M      1555
C     ----------------------------------------------------------------- GS2M      1556
C     INITIALIZE DATA FOR TIME STEP, CHECK FOR STEADY STATE,            GS2M      1557
C     PRINT AND  PUNCH RESULTS                                          GS2M      1558
C     ----------------------------------------------------------------- GS2M      1559
C                                                                       GS2M      1560
C     SPECIFICATIONS:                                                   GS2M      1561
      REAL   MINS,M,KEEP                                                GS2M      1562
      INTEGER R,P,PU,DIML,DIMW,CHK,WATER,CONVRT,EVAP,CHCK,PNCH,NUM,HEAD, GS2M     1563
     1CONTR,LEAK,RECH,SIP,ADI,XLABEL,YLABEL                             GS2M      1564
C                                                                       GS2M      1565
      DIMENSION PHI(  1  ), KEEP(  1  ), STRT(  1  ), SURI(  1  ), T(  1 GS2M     1566
     1  ), BOTTOM(  1  ), WELL(  1  ), PERM(  1  ), TOP(  1  ), DELX( 1) GS2M     1567
     2, DDN( 1), DELY( 1), WR( 1), NWR(  1 ), ITTO(200), TEST3(  1 )    GS2M      1568
     3 ,TR(1),TC(1),S(1),QRE(1),TL(1),SY(1),RATE(1),                    GS2M      1569
     4 RIVER(1),M(1),GRND(1)                                            GS2M      1570
C                                                                       GS2M      1571
      COMMON /SARRAY/ VF4(11),CHK(15),IH                                GS2M      1572
      COMMON /SPARAM/ WATER,CONVRT,EVAP,CHCK,PNCH,NUM,HEAD,CONTR,EROR,LE GS2M     1573
     1AK,RECH,SIP,U,SS,TT,TMIN,ETDIST,QET,ERR,TMAX,CDLT,HMAX,YDIM,WIDTH, GS2M     1574
     2NUMS,LSOR,ADI,DELT,SUM,SUMP,SUBS,STORE,TEST,ETQB,ETQD,FACTX,FACTY, GS2M     1575
     3IERR,KOUNT,IFINAL,NUMT,KT,KP,NPER,KTH,ITMAX,LENGTH,NWEL,NW,DIML,DI GS2M     1576
     4MW,JNO1,INO1,R,P,PU,I,J,IDK1,IDK2,LKPR                            LKPR        12
      COMMON /CK/ ETFLXT,STORT,QRET,CHST,CHDT,FLUXT,PUMPT,CFLUXT,FLXNT  GS2M      1578
      COMMON /PR/ XLABEL(3),YLABEL(6),TITLE(5),XN1,MESUR,PRNT(122),BLANK GS2M     1579
     1(60),DIGIT(122),VF1(6),VF2(6),VF3(7),XSCALE,DINCH,SYM(17),XN(100), GS2M     1580
     2YN(13),NA(4),N1,N2,N3,YSCALE,FACT1,FACT2                          GS2M      1581
C                                                                       GS2M      1582
      DATA PIE/3.141593/                                                GS2M      1583
C     ................................................................. GS2M      1584
C                                                                       GS2M      1585
C     ---START A NEW TIME STEP---                                       GS2M      1586
C     *********************                                             GS2M      1587
      ENTRY NEWSTP                                                      GS2M      1588
C     *********************                                             GS2M      1589
      NB=DIML*DIMW                                                      GS2M      1590
      KT=KT+1                                                           GS2M      1591
      KOUNT=0                                                           GS2M      1592
      DO 10 N=1,NB                                                      GS2M      1593
   10 KEEP( N )=PHI( N )                                                GS2M      1594
      DELT=CDLT*DELT                                                    GS2M      1595
      SUM=SUM+DELT                                                      GS2M      1596
      SUMP=SUMP+DELT                                                    GS2M      1597
      DAYSP=SUMP/86400.                                                 GS2M      1598
      YRSP=DAYSP/365.                                                   GS2M      1599
      HRS=SUM/3600.                                                     GS2M      1600
      MINS=HRS*60.                                                      GS2M      1601
      DAYS=HRS/24.                                                      GS2M      1602
      YRS=DAYS/365.                                                     GS2M      1603
      RETURN                                                            GS2M      1604
C     ................................................................. GS2M      1605
C                                                                       GS2M      1606
C     ---CHECK FOR STEADY STATE---                                      GS2M      1607
C     *********************                                             GS2M      1608
      ENTRY STEADY                                                      GS2M      1609
C     *********************                                             GS2M      1610
      TEST2=0.                                                          GS2M      1611
      DO 20 I=2,INO1                                                    GS2M      1612
      DO 20 J=2,JNO1                                                    GS2M      1613
      N=I+DIML*(J-1)                                                    GS2M      1614
   20 TEST2=AMAX1(TEST2,ABS(KEEP(N)-PHI(N)))                            LKPR8        2
      IF (TEST2.GE.EROR) GO TO 30                                       GS2M      1617
      WRITE (P,330) KT                                                  GS2M      1618
      IFINAL=1                                                          GS2M      1619
      GO TO 40
   30 IF (KT.EQ.NUMT) IFINAL=1
C
C     ---ENTRY FOR TERMINATING COMPUTATIONS IF MAXIMUM ITERATIONS
C     EXCEEDED---
C     **********************
      ENTRY TERM1
C     **********************
   40 IF (KT.GT.200) WRITE (P,400)
      ITTO(KT)=KOUNT
      IF (KOUNT.LE.ITMAX) GO TO 80
      IERR=2
      KOUNT=KOUNT-1
      ITTO(KT)=KOUNT
      IF (KT.EQ.1) GO TO 60
C
C     ---WRITE ON DISK OR PUNCH CARDS AS SPECIFIED IN THE OPTIONS---
      XXX=SUM-DELT
      IF(IDK2.EQ.CHK(15)) WRITE(4)(KEEP(I),I=1,NB)
     1,XXX,SUMP,PUMPT,CFLUXT,QRET,CHST,CHDT,FLUXT,STORT,ETFLXT,FLXNT
      IF (PNCH.NE.CHK(1)) GO TO 80
      WRITE (PU,360) XXX,SUMP,PUMPT,CFLUXT,QRET,CHST,CHDT,FLUXT,STORT,ET
     1FLXT,FLXNT
      DO 50 I=1,DIML
   50 WRITE(PU,350) (KEEP(I+DIML*(J-1)),J=1,DIMW)
      GO TO 80
   60 IF(IDK2.EQ.CHK(15)) WRITE (4)(PHI(I),I=1,NB),SUM,SUMP,PUMPT
     1 ,CFLUXT,QRET,CHST,CHDT,FLUXT,STORT,ETFLXT,FLXNT
      IF (PNCH.NE.CHK(1)) GO TO 80
      WRITE (PU,360) SUM,SUMP,PUMPT,CFLUXT,QRET,CHST,CHDT,FLUXT,STORT,ET
     1FLXT,FLXNT
      DO 70 I=1,DIML
   70 WRITE(PU,350)(PHI(I+DIML*(J-1)),J=1,DIMW)
C
   80 IF(CHCK.EQ.CHK(5)) CALL CHECK(PHI,KEEP,STRT,T,TR,TC,S,QRE,WELL,
     1 TL,SY,RATE,RIVER,M,TOP,GRND,DELX,DELY)
      IF (IERR.EQ.2) GO TO 90
C
C     ---PRINT OUTPUT AT DESIGNATED TIME STEPS---
      IF (MOD(KT,KTH).NE.0.AND.IFINAL.NE.1) RETURN
   90 WRITE (P,340) KT,DELT,SUM,MINS,HRS,DAYS,YRS,DAYSP,YRSP
      IF (CHCK.EQ.CHK(5)) CALL CWRITE
      IF (TT.NE.0.) WRITE (P,320) TMIN,TT
      KOUNT=KOUNT+1
      WRITE (P,300) (TEST3(J),J=1,KOUNT)
      WRITE (P,290) TEST2
      I3=1
      I5=0
  100 I5=I5+40
      I4=MIN0(KT,I5)
      WRITE (P,390) (I,I=I3,I4)
      WRITE (P,380)
      WRITE (P,370) (ITTO(I),I=I3,I4)
      WRITE (P,380)
      IF (KT.LE.I5) GO TO 110
      I3=I3+40
      GO TO 100
C
C     ---PRINT ALPHAMERIC MAPS---
  110 IF (CONTR.NE.CHK(3)) GO TO 120
      IF(FACT1.NE.0.) CALL PRNTA(PHI,SURI,T,S,WELL,DELX,DELY,1)
      IF(FACT2.NE.0.) CALL PRNTA(PHI,SURI,T,S,WELL,DELX,DELY,2)
  120 IF (HEAD.NE.CHK(8)) GO TO 140
C
C     ---PRINT HEAD MATRIX---
      WRITE (P,310)
      DO 130 I=1,DIML
  130 WRITE(P,VF4) I,(PHI(I+DIML*(J-1)),J=1,DIMW)
  140 IF (NUM.NE.CHK(4)) GO TO 170
C
C     ---PRINT DRAWDOWN---
      WRITE (P,280)
C     ********************
      ENTRY DRDN
C     ********************
      DO 160 I=1,DIML
      DO 150 J=1,DIMW
      N=I+DIML*(J-1)
  150 DDN(J)=SURI( N )-PHI( N )
  160 WRITE (P,VF4) I,(DDN(J),J=1,DIMW)
  170 IF (NW.EQ.0.OR.IERR.EQ.1) GO TO 230
C     .................................................................
C
C     ---COMPUTE APPROXIMATE HEAD FOR PUMPING WELLS---
      WRITE (P,260)
      DO 220 KW=1,NW
      IF (WR(KW).EQ.0.) GO TO 220
      I=NWR(KW)
      J=NWR(KW+IW)
      N=I+DIML*(J-1)
C
C     COMPUTE EFFECTIVE RADIUS OF WELL IN MODEL---
      RE=(DELX(J)+DELY(I))/9.62
      IF (WATER.NE.CHK(2)) GO TO 180
      IF (CONVRT.NE.CHK(7)) GO TO 190
      IF (PHI( N ).LT.TOP( N )) GO TO 190
C
C     ---COMPUTATION FOR WELL IN ARTESIAN AQUIFER---
  180 HW=PHI( N )+WELL( N )*ALOG(RE/WR(KW))/(2.*PIE*T( N ))*DELX(J)*DELY
     1(I)
      GO TO 210
C
C     ---COMPUTATION FOR WELL IN WATER TABLE AQUIFER
  190 HED=PHI( N )-BOTTOM( N )
      ARG=HED*HED+WELL( N )*ALOG(RE/WR(KW))/(PIE*PERM( N ))*DELX(J)*DELY
     1(I)
      IF (ARG.GT.0.) GO TO 200
      WRITE (P,270) I,J
      GO TO 220
  200 HW=SQRT(ARG)+BOTTOM( N )
C
C     ---COMPUTE DRAWDOWN AT THE WELL AND PRINT RESULTS---
  210 DRAW=SURI( N )-HW
      WRITE (P,250) I,J,WR(KW),HW,DRAW
  220 CONTINUE
  230 IF (IERR.NE.2) RETURN
      STOP
C
C     ---DISK OUTPUT---
C     ****************
      ENTRY DISK
C     ****************
      WRITE(4)(PHI(I),I=1,NB),SUM,SUMP,PUMPT,CFLUXT,QRET,CHST,
     1 CHDT,FLUXT,STORT,ETFLXT,FLXNT
      RETURN
C     .................................................................
C
C     ---PUNCHED OUTPUT---
C     ********************
      ENTRY PUNCH
C     ********************
      WRITE (PU,360) SUM,SUMP,PUMPT,CFLUXT,QRET,CHST,CHDT,FLUXT,STORT,ET
     1FLXT,FLXNT                                                        GS2M    1752
      DO 240 I=1,DIML                                                   GS2M    1753
  240 WRITE(PU,350)(PHI(I+DIML*(J-1)),J=1,DIMW)                         GS2M    1754
      RETURN                                                            GS2M    1755
C                                                                       GS2M    1756
C     .................................................................. GS2M    1757
C                                                                       GS2M    1758
C     FORMATS:                                                          GS2M    1759
C                                                                       GS2M    1760
C                                                                       GS2M    1761
C     ------------------------------------------------------------------ GS2M    1762
C                                                                       GS2M    1763
C                                                                       GS2M    1764
  250 FORMAT (* *,43X,2I5,3F11.2)                                       GS2M    1765
  260 FORMAT (*-*,50X,*HEAD AND DRAWDOWN IN PUMPING WELLS*/51X,34(*-*)// GS2M    1766
     148X,*I     J   WELL RADIUS    HEAD    DRAWDOWN*//)                GS2M    1767
  270 FORMAT (* *,43X,2I5,*  WELL IS DRY*)                              GS2M    1768
  280 FORMAT (1H1,60X,*DRAWDOWN*/61X,8(*-*))                            GS2M    1769
  290 FORMAT (*0MAXIMUM CHANGE IN HEAD FOR THIS TIME STEP =*,F10.3/* *,5 GS2M    1770
     13(*-*))                                                           GS2M    1771
  300 FORMAT (*0MAXIMUM HEAD CHANGE FOR EACH ITERATION:*/* *,39(*-*)/(*0 GS2M    1772
     1*,10F12.4))                                                       GS2M    1773
  310 FORMAT (*1*,60X,*HEAD MATRIX*/61X,11(*-*))                        GS2M    1774
  320 FORMAT (*0DIMENSIONLESS TIME FOR THIS STEP RANGES FROM*,G15.7,*  T GS2M    1775
     1O*,G15.7)                                                         GS2M    1776
  330 FORMAT (*-$$$$$STEADY STATE AT TIME STEP*,I4,*$$$$$*)             GS2M    1777
  340 FORMAT (1H1,44X,57(*-*)/45X,*&*,14X,*TIME STEP NUMBER =*,I9,14X,*& GS2M    1778
     1*/45X,57(*-*)//50X,29HSIZE OF TIME STEP IN SECONDS=,F14.2//55X,*TO GS2M    1779
     2TAL SIMULATION TIME IN SECONDS=*,F14.2/80X,8HMINUTES=,F14.2/82X,6H GS2M    1780
     3HOURS=,F14.2/83X,5HDAYS=,F14.2/82X,*YEARS=*,F14.2///45X,*DURATION GS2M    1781
     4OF CURRENT PUMPING PERIOD IN DAYS=*,F14.2/82X,*YEARS=*,F14.2//)    GS2M    1782
  350 FORMAT (8F10.4)                                                   GS2M    1783
  360 FORMAT (4G20.10)                                                  GS2M    1784
  370 FORMAT (*0ITERATIONS:*,40I3)                                      GS2M    1785
  380 FORMAT (* *,10(*-*))                                              GS2M    1786
  390 FORMAT (*0TIME STEP :*,40I3)                                      GS2M    1787
  400 FORMAT (*0*,10(1H*),*THE NUMBER OF TIME STEPS EXCEEDS THE DIMENSIO GS2M    1788
     1N OF THE VECTOR ITTO AND MAY CAUSE UNEXPECTED RESULTS IN ADDITIONA GS2M    1789
     2L*/*0COMPUTATION.  AVOID PROBLEMS BY INCREASING THE DIMENSION OF T GS2M    1790
     3HE VECTOR ITTO IN STEP*,10(1H*))                                  GS2M    1791
      END                                                               GS2M    1792
      SUBROUTINE COEF(PHI,KEEP,STRT,SURI,T,TR,TC,S,QRE,WELL,TL,SL,      GS2M    1793
     1 PERM,BOTTOM,SY,RATE,RIVER,M,TOP,GRND,DELX,DDN,DELY,WR,NWR,       GS2M    1794
     2 TEST3)                                                           GS2M    1795
C     ------------------------------------------------------------------ GS2M    1796
C     COMPUTE COEFFICIENTS                                              GS2M    1797
C     ------------------------------------------------------------------ GS2M    1798
C                                                                       GS2M    1799
C     SPECIFICATIONS:                                                   GS2M    1800
      REAL   KEEP,M                                                     GS2M    1801
      INTEGER R,P,PU,DIML,DIMW,CHK,WATER,CONVRT,EVAP,CHCK,PNCH,NUM,HEAD, GS2M    1802
     1CONTR,LEAK,RECH,SIP,ADI                                           GS2M    1803
C                                                                       GS2M    1804
      DIMENSION PHI(1), KEEP(1), PHE(1), STRT(1), SURI(1), T(1), TR(1), GS2M    1805
     1TC(1), S(1), WELL(1), TL(1), SL(1), PERM(1), BOTTOM(1), SY(1), RAT GS2M    1806
     2E(1), RIVER(1), M(1), TOP(1), GRND(1), DELX(1), DELY(1)           GS2M    1807
     3 ,QRE(1),DDN(1),WR(1),NWR(1),TEST3(1)                             GS2M    1808
C                                                                       GS2M    1809
      COMMON /SARRAY/ VF4(11),CHK(15),IH                                GS2M    1810
      COMMON /SPARAM/ WATER,CONVRT,EVAP,CHCK,PNCH,NUM,HEAD,CONTR,EROR,LE GS2M    1811
     1AK,RECH,SIP,U,SS,TT,TMIN,ETDIST,QET,ERR,TMAX,CDLT,HMAX,YDIM,WIDTH, GS2M    1812
     2NUMS,LSOR,ADI,DELT,SUM,SUMP,SUBS,STORE,TEST,ETQB,ETQD,FACTX,FACTY, GS2M    1813
     3IERR,KOUNT,IFINAL,NUMT,KT,KP,NPER,KTH,ITMAX,LENGTH,NWEL,NW,DIML,DI GS2M    1814
     4MW,JNO1,INO1,R,P,PU,I,J,IDK1,IDK2,LKPR                            LKPR      13
C                                                                       GS2M    1816
      DATA PIE/3.141593/                                                GS2M    1817
```

```
C     ..............................................................
C
C     ---COMPUTE COEFFICIENTS FOR TRANSIENT PART OF LEAKAGE TERM---
C     *********************
      ENTRY CLAY
C     *********************
      TMIN=1.E30
      TT=0.0
      PRATE=0.
      DO 50 I=1,DIML
      DO 50 J=1,DIMW
      N=I+DIML*(J-1)
C
C     ---SKIP COMPUTATIONS IF T, RATE OR M = 0, OR IF CONSTANT
C        HEAD BOUNDARY---
      IF (RATE(N).LE.0..OR.T(N).EQ.0..OR.M(N).EQ.0..OR.S(N).LT.0.) GO TO
     1 50
C
C     ---IF VALUE FOR TL(N  ) WILL EQUAL VALUE FOR PREVIOUS NODE,
C     SKIP PART OF COMPUTATIONS---
      IF (RATE(N)*M(N).EQ.PRATE) GO TO 40
      DIMT=RATE(N)*SUMP/(M(N)*M(N)*SS*3)
      IF (DIMT.GT.TT) TT=DIMT
      IF (DIMT.LT.TMIN) TMIN=DIMT
      PPT=PIE*PIE*DIMT
C
C     ---RECOMPUTE PPT IF DIMT WITHIN RANGE FOR SHORT TIME COMPUTATION--
      IF (DIMT.LT.1.0E-03) PPT=1.0/DIMT
      CC=(2.3-PPT)/(2.*PPT)
C
C     ---COMPUTE SUM OF EXPONENTIALS---
      SUMN=0.0
      DO 20 K=1,200
      POWER=K*K*PPT
      IF (POWER.LE.150.) GO TO 10
      POWER=150
   10 PEX=EXP(-POWER)
      SUMN=SUMN+PEX
      IF (PEX.GT.0.00009) GO TO 20
      IF (K.GT.CC) GO TO 30
   20 CONTINUE
C
C     ---COMPUTE DENOMINATER DEPENDING ON VALUE OF DIMT---
   30 DENOM=1.0
      IF (DIMT.LT.1.0E-03) DENOM=SQRT(PIE*DIMT)
C
C     ---HEAD VALUES ARE NOT INCLUDED IN COMPUTATION OF Q FACTOR SINCE
C        LEAKAGE IS CONSIDERED IMPLICITLY---
   40 Q1=RATE(N)/(M(N)*DENOM)
      TL(N)=Q1+2.*Q1*SUMN
      PRATE=RATE(N)*M(N)
   50 CONTINUE
      TMIN=TMIN*3.0
      TT=TT*3.0
      RETURN
C     ..............................................................
C
C     ---COMPUTE TRANSMISSIVITY IN WT OR WT-ARTESIAN CONVERSION PROBLEM-
C     *********************
      ENTRY TRANS
C     *********************
      DO 60 I=1,DIML
      DO 60 J=1,DIMW
      N=I+DIML*(J-1)
      IF (PERM(N).EQ.0.) GO TO 60
      HED=PHI(N)
      IF (CONVRT.EQ.CHK(7)) HED=AMIN1(PHI(N),TOP(N))
      T(N)=PERM(N)*(HED-BOTTOM(N))
      IF (T(N).GT.0.) GO TO 60
      IF (WELL(N).LT.0.) GO TO 70
C
C     ---THE FOLLOWING STATEMENTS APPLY WHEN NODES (EXCEPT WELL NODES)
C     GO DRY---
      PHI(N)=0.01*(SURI(N)-BOTTOM(N))+BOTTOM(N)
      WRITE (P,150) I,J
   60 CONTINUE
      IF (KT.EQ.0) RETURN
      GO TO 90
C
C     ---START PROGRAM TERMINATION WHEN A WELL GOES DRY---
   70 WRITE (P,120) I,J
      WRITE (P,130)
      IERR=1
      CALL DRDN(PHI,KEEP,STRT,SURI,T,TR,TC,S,QRE,WELL,TL,PERM,BOTTOM,
     1SY,RATE,RIVER,M,TOP,GRND,DELX,DDN,DELY,WR,NWR,TEST3)
      DO 80 I=2,INO1
      DO 80 J=2,JNO1
      N=I+DIML*(J-1)
   80 PHI(N)=KEEP(N)
      SUM=SUM-DELT
      SUMP=SUMP-DELT
      KT=KT-1
      IF (KT.EQ.0) STOP
      IF(IDK2.EQ.CHK(15)) CALL DISK(PHI,KEEP,STRT,
     1 SURI,T,TR,TC,S,QRE,WELL,TL,PERM,BOTTOM,SY,RATE,RIVER,
     2 M,TOP,GRND,DELX,DDN,DELY,WR,NWR,TEST3)
       IF(PNCH.EQ.CHK(1)) CALL PUNCH(PHI,KEEP,STRT,SURI,T,TR,TC,S,QRE,
     1 WELL,TL,PERM,BOTTOM,SY,RATE,RIVER,M,TOP,GRND,DELX,DDN,DELY,
     2 WR,NWR,TEST3)
       IF (MOD(KT,KTH).EQ.0) STOP
      WRITE (P,140) KT,SUM
      CALL DRDN(PHI,KEEP,STRT,SURI,T,TR,TC,S,QRE,WELL,TL,PERM,BOTTOM,
     1SY,RATE,RIVER,M,TOP,GRND,DELX,DDN,DELY,WR,NWR,TEST3)
      IF (CHCK.EQ.CHK(5)) CALL CWRITE
      STOP
C
C     ---COMPUTE T COEFFICIENTS---
C     ********************
      ENTRY TCOF
C     ********************
   90 DO 110 I=1,INO1
      DO 110 J=1,JNO1
      N=I+DIML*(J-1)
      NR=N+DIML
      NB=N+1
      IF (T(N).EQ.0.) GO TO 110
      IF (T(NR).EQ.0.) GO TO 100
      TR(N)=(2.*T(NR)*T(N))/(T(N)*DELX(J+1)+T(NR)*DELX(J))*FACTX
  100 IF (T(NB).EQ.0.) GO TO 110
      TC(N)=(2.*T(NB)*T(N))/(T(N)*DELY(I+1)+T(NB)*DELY(I))*FACTY
  110 CONTINUE
      RETURN
C
C     ---FORMATS---
C
C     ------------------------------------------------------------------
C
C
  120 FORMAT (*-$$$$$$$$$$$$$$WELL*,I3,*,*,I3,* GOES DRY$$$$$$$$$$$$$$$*)
  130 FORMAT (*1*,50X,*DRAWDOWN WHEN WELL WENT DRY*)
  140 FORMAT (*1*,32X,*DRAWDOWN FOR TIME STEP*,I3,*; SIMULATION TIME =*,
     11PE15.7,* SECONDS*)
  150 FORMAT (*-*,20(1H*),* NODE *,I4,*,*,I4,* GOES DRY *,20(1H*))        GS2M      1956
      END                                                                 GS2M      1957
      SUBROUTINE CHECKI(PHI,KEEP,     STRT,T,TR,TC,S,QRE,WELL,TL,         GS2M      1958
     1     SY,RATE,RIVER,M,TOP,GRND,DELX,DELY     )                       GS2M      1959
C     ------------------------------------------------------------------ GS2M      1960
C     COMPUTE A MASS BALANCE                                              GS2M      1961
C     ------------------------------------------------------------------ GS2M      1962
C                                                                         GS2M      1963
C     SPECIFICATIONS:                                                     GS2M      1964
      REAL   KEEP,M                                                       GS2M      1965
      INTEGER R,P,PU,DIML,DIMW,CHK,WATER,CONVRT,EVAP,CHCK,PNCH,NUM,HEAD,  GS2M      1966
     1CONTR,LEAK,RECH,SIP,ADI                                             GS2M      1967
C                                                                         GS2M      1968
      DIMENSION PHI(  1  ), KEEP(  1  ), PHE(  1  ), STRT(  1  ), T(  1   GS2M      1969
     1 ), TR(  1  ), TC(  1  ), S(  1  ), QRE(  1  ), WELL(  1  ), TL(    GS2M      1970
     21  ), PERM(  1  ), BOTTOM(  1  ), SY(  1  ), RATE(  1  ), RIVER(    GS2M      1971
     31  ), M(  1  ), TOP(  1  ), GRND(  1  ), DELX( 1), DELY( 1)         GS2M      1972
C                                                                         GS2M      1973
      COMMON /SARRAY/ VF4(11),CHK(15),IH                                  GS2M      1974
      COMMON /SPARAM/ WATER,CONVRT,EVAP,CHCK,PNCH,NUM,HEAD,CONTR,EROR,LE  GS2M      1975
     1AK,RECH,SIP,U,SS,TT,TMIN,ETDIST,QET,ERR,TMAX,CDLT,HMAX,YDIM,WIDTH,  GS2M      1976
     2NUMS,LSOR,ADI,DELT,SUM,SUMP,SUBS,STORE,TEST,ETQB,ETQD,FACTX,FACTY,  GS2M      1977
     3IERR,KOUNT,IFINAL,NUMT,KT,KP,NPER,KTH,ITMAX,LENGTH,NWEL,NW,DIML,DI  GS2M      1978
     4MW,JNO1,INO1,R,P,PU,I,J,IDK1,IDK2,LKPR                              LKPR        14
      COMMON /CK/ ETFLXT,STORT,QRET,CHST,CHDT,FLUXT,PUMPT,CFLUXT,FLXNT    GS2M      1980
      DIMENSION DUM1(60),DUM2(60),DUM3(60)                                LKPR2       17
C     .................................................................. GS2M      1981
C     ********************                                                GS2M      1982
      ENTRY CHECK                                                         GS2M      1983
C     ********************                                                GS2M      1984
C     ---INITIALIZE VARIABLES---                                          GS2M      1985
      PUMP=0.                                                             GS2M      1986
      STOR=0.                                                             GS2M      1987
      FLUXS=0.0                                                           GS2M      1988
      CHD1=0.0                                                            GS2M      1989
      CHD2=0.0                                                            GS2M      1990
      QREFLX=0.                                                           GS2M      1991
      CFLUX=0.                                                            GS2M      1992
      FLUX=0.                                                             GS2M      1993
      ETFLUX=0.                                                           GS2M      1994
      FLXN=0.0                                                            GS2M      1995
C     .................................................................. GS2M      1996
C                                                                         GS2M      1997
C     ---COMPUTE RATES,STORAGE AND PUMPAGE FOR THIS STEP---               GS2M      1998
      JLAST=DIMW-1                                                        LKPR        16
      DO 245 I=2,DIML                                                     LKPR        17
      DO 240 J=2,DIMW                                                     GS2M      2000
      DUM1(J)=0.0                                                         LKPR2       18
      DUM2(J)=0.0                                                         LKPR2       19
      DUM3(J)=0.0                                                         LKPR2       20
      N=I+DIML*(J-1)                                                      GS2M      2001
      IF (T( N ).EQ.0.) GO TO 240                                         GS2M      2002
      AREA=DELX(J)*DELY(I)                                                GS2M      2003
      IF (S( N ).GE.0.) GO TO 120                                         GS2M      2004
      X1=0.0                                                              LKPR        18
C                                                                         GS2M      2005
C     ---COMPUTE FLOW RATES TO AND FROM CONSTANT HEAD BOUNDARIES---       GS2M      2006
      IF (S(N-DIML).LT.0..OR.T(N-DIML).EQ.0.) GO TO 30                    GS2M      2007
      X=(STRT( N )-PHI(N-DIML))*TR(N-DIML)*DELY(I)                        GS2M      2008
      X1=X1+X                                                             LKPR        19
      IF (X) 10,30,20                                                     GS2M      2009
   10 CHD1=CHD1+X                                                         GS2M      2010
      GO TO 30                                                            GS2M      2011
   20 CHD2=CHD2+X                                                         GS2M      2012
   30 IF (S(N+DIML).LT.0..OR.T(N+DIML).EQ.0.) GO TO 60                    GS2M      2013
      X=(STRT( N )-PHI(N+DIML))*TR( N )*DELY(I)                           GS2M      2014
      X1=X1+X
      IF (X) 40,60,50                                                   LKPR      20
   40 CHO1=CHO1+X                                                       GS2M    2015
      GO TO 60                                                          GS2M    2016
   50 CHO2=CHO2+X                                                       GS2M    2017
   60 IF (S( N-1 ).LT.0..OR.T( N-1 ).EQ.0.) GO TO 90                   GS2M    2018
      X=(STRT( N )-PHI( N-1 ))*TC( N-1 )*DELX(J)                        GS2M    2019
      X1=X1+X                                                           GS2M    2020
      IF (X) 70,90,80                                                   LKPR      21
   70 CHO1=CHO1+X                                                       GS2M    2021
      GO TO 90                                                          GS2M    2022
   80 CHO2=CHO2+X                                                       GS2M    2023
   90 IF(S(N+1).LT.0.0.OR.T(N+1).EQ.0) GO TO 115                        GS2M    2024
      X=(STRT( N )-PHI( N+1 ))*TC( N )*DELX(J)                          LKPT1      1
      X1=X1+X                                                           GS2M    2026
      IF (X) 100,115,110                                                LKPT1      2
  100 CHO1=CHO1+X                                                       LKPR8      4
      GO TO 115                                                         GS2M    2028
  110 CHO2=CHO2+X                                                       LKPR8      5
  115 CONTINUE                                                          GS2M    2030
      DUM1(J)=X1                                                        LKPT1      3
      GO TO 240                                                         LKPR      23
C                                                                       GS2M    2031
C     ---RECHARGE AND WELLS---                                          GS2M    2032
  120 QREFLX=QREFLX+QRE( N )*AREA                                       GS2M    2033
      DUM1(J)=0.0                                                       GS2M    2034
      IF (WELL( N )) 130,150,140                                        LKPR      24
  130 PUMP=PUMP+WELL( N )*AREA                                          GS2M    2035
      GO TO 150                                                         GS2M    2036
  140 CFLUX=CFLUX+WELL( N )*AREA                                        GS2M    2037
  150 IF (EVAP.NE.CHK(6)) GO TO 190                                     GS2M    2038
C                                                                       GS2M    2039
C     ---COMPUTE ET RATE---                                             GS2M    2040
      IF (PHI( N ).GE.GRND( N )-ETDIST) GO TO 160                       GS2M    2041
      ETQ=0.0                                                           GS2M    2042
      GO TO 180                                                         GS2M    2043
  160 IF (PHI( N ).LE.GRND( N )) GO TO 170                              GS2M    2044
      ETQ=QET                                                           GS2M    2045
      GO TO 180                                                         GS2M    2046
  170 ETQ=QET/ETDIST*(PHI( N )+ETDIST-GRND( N ))                        GS2M    2047
      DUM3(J)=ETQ*AREA                                                  GS2M    2048
  180 ETFLUX=ETFLUX-ETQ*AREA                                            LKPR2     21
C                                                                       GS2M    2049
C     ---COMPUTE VOLUME FROM STORAGE---                                 GS2M    2050
  190 STORE=S( N )                                                      GS2M    2051
      IF (WATER.EQ.CHK(2)) STORE=SY( N )                                GS2M    2052
      IF (CONVRT.NE.CHK(7)) GO TO 230                                   GS2M    2053
      X=KEEP( N )-PHI( N )                                              GS2M    2054
      IF (X) 200,210,210                                                GS2M    2055
  200 HED1=PHI( N )                                                     GS2M    2056
      HED2=KEEP( N )                                                    GS2M    2057
      X=ABS(X)                                                          GS2M    2058
      GO TO 220                                                         GS2M    2059
  210 HED1=KEEP( N )                                                    GS2M    2060
      HED2=PHI( N )                                                     GS2M    2061
  220 STORE=S( N )                                                      GS2M    2062
      IF (HED1-TOP( N ).LE.0.) STORE=SY( N )                            GS2M    2063
      IF ((HED1-TOP( N ))*(HED2-TOP( N )).LT.0.0) STORE=(HED1-TOP( N ))/ GS2M    2064
     1X*S( N )+(TOP( N )-HED2)/X*SY( N )                                GS2M    2065
  230 STOR=STOR+STORE*(KEEP( N )-PHI( N ))*AREA                         GS2M    2066
C                                                                       GS2M    2067
C     ---COMPUTE LEAKAGE RATE---                                        GS2M    2068
      DUM2(J)=0.0                                                       GS2M    2069
      IF (LEAK.NE.CHK(4)) GO TO 240                                     LKPR      25
      IF (M( N ).EQ.0.) GO TO 240                                       GS2M    2070
      HED1=STRT( N )                                                    GS2M    2071
                                                                        GS2M    2072
      IF (CONVRT.EQ.CHK(7)) HED1=AMAX1(STRT( N ),TOP( N ))               GS2M    2073
      HED2=PHI( N )                                                      GS2M    2074
      IF (CONVRT.EQ.CHK(7)) HED2=AMAX1(      PHI( N ) ,TOP( N ))         GS2M    2075
      XX=RATE( N )*(RIVER( N )-HED1)*AREA/M( N )                         GS2M    2076
      YY=TL( N )*(HED1-HED2)*AREA                                        GS2M    2077
      FLUX=FLUX+XX                                                       GS2M    2078
      XNET=XX+YY                                                         GS2M    2079
      DUM2(J)=XNET                                                       LKPR      26
      FLUXS=FLUXS+XNET                                                   GS2M    2080
      IF (XNET.LT.0.) FLXN=FLXN-XNET                                     GS2M    2081
  240 CONTINUE                                                           GS2M    2082
      IF(I.EQ.DIML) GO TO 245                                            LKPR      27
      IF(LKPR.EQ.0) GO TO 245                                            LKPR      28
      IF(MOD(KT,LKPR).NE.0.AND.IFINAL.NE.1) GO TO 245                    LKPR      29
      WRITE(P,270) I                                                     LKPR      30
      WRITE(P,280) (DUM1(J),J=2,JLAST)                                   LKPR      31
      IF(LEAK.NE.CHK(9)) GO TO 242                                       LKPR2     22
      WRITE(P,290)                                                       LKPR      32
      WRITE(P,280) (DUM2(J),J=2,JLAST)                                   LKPR      33
  242 CONTINUE                                                           LKPR2     23
      IF(EVAP.NE.CHK(6)) GO TO 245                                       LKPR2     24
      WRITE (P,300)                                                      LKPR2     25
      WRITE (P,280) (DUM3(J),J=2,JLAST)                                  LKPR2     26
  245 CONTINUE                                                           LKPR      34
C     .................................................................. GS2M    2083
C                                                                        GS2M    2084
C     ---COMPUTE CUMULATIVE VOLUMES, TOTALS, AND DIFFERENCES---          GS2M    2085
      STORT=STORT+STOR                                                   GS2M    2086
      STOR=STOR/DELT                                                     GS2M    2087
      ETFLXT=ETFLXT-ETFLUX*DELT                                          GS2M    2088
      FLUXT=FLUXT+FLUXS*DELT                                             GS2M    2089
      FLXNT=FLXNT+FLXN*DELT                                              GS2M    2090
      FLXPT=FLUXT+FLXNT                                                  GS2M    2091
      QRET=QRET+QREFLX*DELT                                              GS2M    2092
      CHDT=CHDT-CHD1*DELT                                                GS2M    2093
      CHST=CHST+CHD2*DELT                                                GS2M    2094
      PUMPT=PUMPT-PUMP*DELT                                              GS2M    2095
      CFLUXT=CFLUXT+CFLUX*DELT                                           GS2M    2096
      TOTL1=STORT+QRET+CFLUXT+CHST+FLXPT                                 GS2M    2097
      TOTL2=CHDT+PUMPT+ETFLXT+FLXNT                                      GS2M    2098
      SUMR=QREFLX+CFLUX+CHD2+CHD1+PUMP+ETFLUX+FLUXS+STOR                 GS2M    2099
      DIFF=TOTL2-TOTL1                                                   GS2M    2100
      PERCNT=0.0                                                         GS2M    2101
      IF (TOTL2.EQ.0.) GO TO 250                                         GS2M    2102
      PERCNT=DIFF/TOTL2*100.                                             GS2M    2103
  250 RETURN                                                             GS2M    2104
C     .................................................................. GS2M    2105
C                                                                        GS2M    2106
C     ---PRINT RESULTS---                                                GS2M    2107
C     ************************                                           GS2M    2108
      ENTRY CWRITE                                                       GS2M    2109
C     ************************                                           GS2M    2110
C                                                                        GS2M    2111
      WRITE (P,260) STOR,QREFLX,STORT,CFLUX,QRET,PUMP,CFLUXT,ETFLUX,CHST GS2M    2112
     1,FLXPT,CHD2,TOTL1,CHD1,FLUX,FLUXS,ETFLXT,CHDT,SUMR,PUMPT,FLXNT,TOT GS2M    2113
     2L2,DIFF,PERCNT                                                     GS2M    2114
      RETURN                                                             GS2M    2115
C                                                                        GS2M    2116
C     ---FORMATS---                                                      GS2M    2117
C                                                                        GS2M    2118
C     ------------------------------------------------------------------ GS2M    2119
C                                                                        GS2M    2120
C                                                                        GS2M    2121
  260 FORMAT (*0*,10X,*CUMULATIVE MASS BALANCE:*,16X,4HL**3,23X,*RATES F GS2M    2122
     1OR THIS TIME STEP:*,16X,6HL**3/T/11X,24(*-*),43X,25(*-*)//20X,*SOU GS2M    2123
     2RCES:*,69X,*STORAGE =*,F20.4/20X,8(*-*),68X,*RECHARGE =*,F20.4/27X GS2M    2124
     3,*STORAGE =*,F20.2,35X,*CONSTANT FLUX =*,F20.4/26X,*RECHARGE =*,F2 GS2M      2125
     40.2,41X,*PUMPING =*,F20.4/21X,*CONSTANT FLUX =*,F20.2,30X,*EVAPOTR GS2M      2126
     5ANSPIRATION =*,F20.4/21X,*CONSTANT HEAD =*,F20.2,34X,*CONSTANT HEA GS2M      2127
     6D:*/27X,*LEAKAGE =*,F20.2,46X,*IN =*,F20.4/21X,*TOTAL SOURCES =*,F GS2M      2128
     720.2,45X,*OUT =*,F20.4/96X,*LEAKAGE:*/20X,*DISCHARGES:*,45X,*FROM  GS2M      2129
     8PREVIOUS PUMPING PERIOD =*,F20.4/20X,11(*-*),68X,*TOTAL =*,F20.4/1 GS2M      2130
     96X,*EVAPOTRANSPIRATION =*,F20.2/21X,*CONSTANT HEAD =*,F20.2,36X,*S GS2M      2131
     $UM OF RATES =*,F20.4/19X*QUANTITY PUMPED =*,F20.2/27X,*LEAKAGE =*, GS2M      2132
     $F20.2/19X,*TOTAL DISCHARGE =*,F20.2//17X,*DISCHARGE-SOURCES =*,F20 GS2M      2133
     $.2/15X,*PER CENT DIFFERENCE =*,F20.2//)                            GS2M      2134
  270 FORMAT(/10X,*ROW*,I5/20X,*CONSTANT HEAD FLUX RATES ... LLL/T*)     LKPR        35
  280 FORMAT(2X,12G10.3)                                                 LKPR        36
  290 FORMAT(20X,*LEAKAGE RATES ... LLL/T*)                              LKPR        37
  300 FORMAT(20X,*ET RATES ... LLL/T*)                                   LKPR2       27
      END                                                                GS2M      2135
      SUBROUTINE PRNTAI(PHI,SURI,T,S,WELL,DELX,DELY,NG)                  GS2M      2136
C     ---------------------------------------------------------------- GS2M      2137
C     PRINT MAPS OF DRAWDOWN AND HYDRAULIC HEAD                          GS2M      2138
C     ---------------------------------------------------------------- GS2M      2139
C                                                                        GS2M      2140
C     SPECIFICATIONS:                                                    GS2M      2141
      REAL   K                                                           GS2M      2142
      INTEGER R,P,PU,DIML,DIMW,CHK,WATER,CONVRT,EVAP,CHCK,PNCH,NUM,HEAD, GS2M      2143
     1CONTR,LEAK,RECH,SIP,ADI,XLABEL,YLABEL                              GS2M      2144
C                                                                        GS2M      2145
      DIMENSION PHI(  1  ), SURI(  1  ), S(  1  ), WELL(  1  ), DELX( 1) GS2M      2146
     1, DELY( 1), T(  1  )                                               GS2M      2147
C                                                                        GS2M      2148
      COMMON /SARRAY/ VF4(11),CHK(15),IH                                 GS2M      2149
      COMMON /SPARAM/ WATER,CONVRT,EVAP,CHCK,PNCH,NUM,HEAD,CONTR,EROR,LE GS2M      2150
     1AK,RECH,SIP,U,SS,TT,TMIN,ETDIST,QET,ERR,TMAX,CDLT,HMAX,YDIM,WIDTH, GS2M      2151
     2NUMS,LSOR,ADI,DELT,SUM,SUMP,SUBS,STORE,TEST,ETQB,ETQD,FACTX,FACTY, GS2M      2152
     3IERR,KOUNT,IFINAL,NUMT,KT,KP,NPER,KTH,ITMAX,LENGTH,NWEL,NW,DIML,DI GS2M      2153
     4MW,JNO1,INO1,R,P,PU,I,J,IDK1,IDK2,LKPR                             LKPR        38
      COMMON /PR/ XLABEL(3),YLABEL(6),TITLE(5),XN1,MESUR,PRNT(122),BLANK GS2M      2155
     1(60),DIGIT(122),VF1(6),VF2(6),VF3(7),XSCALE,DINCH,SYM(17),XN(100), GS2M      2156
     2YN(13),NA(4),N1,N2,N3,YSCALE,FACT1,FACT2                           GS2M      2157
C     ................................................................ GS2M      2158
C                                                                        GS2M      2159
C     ---INITIALIZE VARIABLES FOR PLOT---                                GS2M      2160
C     ********************                                               GS2M      2161
      ENTRY MAP                                                          GS2M      2162
C     ********************                                               GS2M      2163
   10 XSF=DINCH*XSCALE                                                   GS2M      2164
      YSF=DINCH*YSCALE                                                   GS2M      2165
      NYD=YDIM/YSF                                                       GS2M      2166
      IF (NYD*YSF.LE.YDIM-DELY(INO1)/2.) NYD=NYD+1                       GS2M      2167
      IF (NYD.LE.12) GO TO 20                                            GS2M      2168
      DINCH=YDIM/(12.*YSCALE)                                            GS2M      2169
      WRITE (P,310) DINCH                                                GS2M      2170
      IF (YSCALE.LT.1.0) WRITE (P,320)                                   GS2M      2171
      GO TO 10                                                           GS2M      2172
   20 NXD=WIDTH/XSF                                                      GS2M      2173
      IF (NXD*XSF.LE.WIDTH-DELX(JNO1)/2.) NXD=NXD+1                      GS2M      2174
      N4=NXD*N1+1                                                        GS2M      2175
      N5=NXD+1                                                           GS2M      2176
      N6=NYD+1                                                           GS2M      2177
      N8=N2*NYD+1                                                        GS2M      2178
      NA(1)=N4/2-1                                                       GS2M      2179
      NA(2)=N4/2                                                         GS2M      2180
      NA(3)=N4/2+3                                                       GS2M      2181
      NC=(N3-N8-10)/2                                                    GS2M      2182
      ND=NC+N8                                                           GS2M      2183
      NE=MAX0(N5,N6)                                                     GS2M      2184
      VF1(3)=DIGIT(ND)                                                   GS2M      2185
      VF2(3)=DIGIT(ND)                                                   GS2M      2186
      NF3(3)=DIGIT(NC)                                                  GS2M    2187
      XLABEL(3)=MESUR                                                   GS2M    2188
      YLABEL(6)=MESUR                                                   GS2M    2189
      DO 40 I=1,NE                                                      GS2M    2190
      NNX=NS-I                                                          GS2M    2191
      NNY=I-1                                                           GS2M    2192
      IF (NNY.GE.N6) GO TO 30                                           GS2M    2193
      YN(I)=YSF*NNY/YSCALE                                              GS2M    2194
   30 IF (NNX.LT.0) GO TO 40                                            GS2M    2195
      XN(I)=XSF*NNX/YSCALE                                              GS2M    2196
   40 CONTINUE                                                          GS2M    2197
      RETURN                                                            GS2M    2198
C     ..............................................................    GS2M    2199
C                                                                       GS2M    2200
C     ********************                                              GS2M    2201
      ENTRY PRNTA                                                       GS2M    2202
C     ********************                                              GS2M    2203
C     ---VARIABLES INITIALIZED EACH TIME A PLOT IS REQUESTED---         GS2M    2204
      DIST=WIDTH-DELX(JNO1)/2.                                          GS2M    2205
      JJ=JNO1                                                           GS2M    2206
      LL=1                                                              GS2M    2207
      Z=NXO*XSF                                                         GS2M    2208
      IF (NG.EQ.1) WRITE (P,280) (TITLE(I),I=1,2)                       GS2M    2209
      IF (NG.EQ.2) WRITE (P,280) (TITLE(I),I=3,5)                       GS2M    2210
      DO 270 I=1,N4                                                     GS2M    2211
C                                                                       GS2M    2212
C     ---LOCATE X AXES---                                               GS2M    2213
      IF (I.EQ.1.OR.I.EQ.N4) GO TO 50                                   GS2M    2214
      PRNT(1)=SYM(12)                                                   GS2M    2215
      PRNT(N8)=SYM(12)                                                  GS2M    2216
      IF ((I-1)/N1*N1.NE.I-1) GO TO 70                                  GS2M    2217
      PRNT(1)=SYM(14)                                                   GS2M    2218
      PRNT(N8)=SYM(14)                                                  GS2M    2219
      GO TO 70                                                          GS2M    2220
C                                                                       GS2M    2221
C     ---LOCATE Y AXES---                                               GS2M    2222
   50 DO 60 J=1,N8                                                      GS2M    2223
      IF ((J-1)/N2*N2.EQ.J-1) PRNT(J)=SYM(14)                           GS2M    2224
   60 IF ((J-1)/N2*N2.NE.J-1) PRNT(J)=SYM(13)                           GS2M    2225
C                                                                       GS2M    2226
C     ---COMPUTE LOCATION OF NODES AND DETERMINE APPROPRIATE SYMBOL---  GS2M    2227
   70 IF (DIST.LT.0..OR.DIST.LT.Z-XN1*XSF) GO TO 220                    GS2M    2228
      YLEN=DELY(2)/2.                                                   GS2M    2229
      DO 200 L=2,INO1                                                   GS2M    2230
      J=YLEN*N2/YSF+1.5                                                 GS2M    2231
      N=L+DIML*(JJ-1)                                                   GS2M    2232
      IF (T( N  ).EQ.0.) GO TO 140                                      GS2M    2233
      IF (S( N  ).LT.0.) GO TO 190                                      GS2M    2234
      INDX3=0                                                           GS2M    2235
      GO TO (80,90), NG                                                 GS2M    2236
   80 K=(SURI( N  )-PHI( N  ))*FACT1                                    GS2M    2237
C     -TO CYCLE SYMBOLS FOR DRAWDOWN, REMOVE C FROM COL. 1 OF NEXT CARD- GS2M    2238
C     K=AMOD(K,10.)                                                     GS2M    2239
      GO TO 100                                                         GS2M    2240
   90 K=PHI( N  )*FACT2                                                 GS2M    2241
  100 IF (K) 110,140,120                                                GS2M    2242
  110 IF (J-2.GT.0) PRNT(J-2)=SYM(13)                                   GS2M    2243
      N=-K                                                              GS2M    2244
      IF (N.LT.100) GO TO 130                                           GS2M    2245
      GO TO 170                                                         GS2M    2246
  120 N=K                                                               GS2M    2247
      IF (N.LT.100) GO TO 130                                           GS2M    2248
      IF (N.GT.999) GO TO 170                                           GS2M    2249
      INDX3=N/100                                                       GS2M    2250
      IF (J-2.GT.0) PRNT(J-2)=SYM(INDX3)                                GS2M    2251
      N=N-INDX3*100                                                     GS2M    2252
  130 INDX1=MOD(N,10)
      IF (INDX1.EQ.0) INDX1=10
C     -TO CYCLE SYMBOLS FOR DRAWDOWN, REMOVE C FROM COL. 1 OF NEXT CARD-
C     IF (NG.EQ.1) GO TO 150
      INDX2=N/10
      IF (INDX2.GT.0) GO TO 160
      INDX2=10
      IF (INDX3.EQ.0) INDX2=15
      GO TO 160
  140 INDX1=15
  150 INDX2=15
  160 IF (J-1.GT.0) PRNT(J-1)=SYM(INDX2)
      PRNT(J)=SYM(INDX1)
      GO TO 200
  170 DO 180 II=1,3
      JI=J-3+II
  180 IF (JI.GT.0) PRNT(JI)=SYM(11)
  190 IF (S( N  ).LT.0.) PRNT(J)=SYM(16)
  200 YLEN=YLEN+(DELY(L)+DELY(L+1))/2.
  210 DIST=DIST-(DELX(JJ)+DELX(JJ-1))/2.
      JJ=JJ-1
      IF (JJ.EQ.0) GO TO 220
      IF (DIST.GT.Z-XN1*XSF) GO TO 210
  220 CONTINUE
C
C     ---PRINT AXES,LABELS, AND SYMBOLS---
      IF (I-NA(LL).EQ.0) GO TO 240
      IF ((I-1)/N1*N1-(I-1)) 250,230,250
  230 WRITE (P,VF1) (BLANK(J),J=1,NC),(PRNT(J),J=1,N8),XN(1+(I-1)/6)
      GO TO 260
  240 WRITE (P,VF2) (BLANK(J),J=1,NC),(PRNT(J),J=1,N8),XLABEL(LL)
      LL=LL+1
      GO TO 260
  250 WRITE (P,VF2) (BLANK(J),J=1,NC),(PRNT(J),J=1,N8)
C
C     ---COMPUTE NEW VALUE FOR Z AND INITIALIZE PRNT---
  260 Z=Z-2.*XN1*XSF
      DO 270 J=1,N8
  270 PRNT(J)=SYM(15)
C
C     ---NUMBER AND LABEL Y AXIS AND PRINT LEGEND---
      WRITE (P,VF3) (BLANK(J),J=1,NC),(YN(I),I=1,N6)
      WRITE (P,300) (YLABEL(I),I=1,6)
      IF (NG.EQ.1) WRITE (P,290) FACT1
      IF (NG.EQ.2) WRITE (P,290) FACT2
      RETURN
C
C     ---FORMATS---
C
C     -----------------------------------------------------------------
C
C
  280 FORMAT (*1*,53X,4A8//)
  290 FORMAT (*0EXPLANATION*/* *,11(*-*)//* R = CONSTANT HEAD BOUNDARY*/
     1* $$$ = VALUE EXCEEDED 3 FIGURES*/* MULTIPLICATION FACTOR =*,F8.3)
  300 FORMAT (*0*,39X,6A8)
  310 FORMAT (*0*,25X,10(1H*),* TO FIT MAP WITHIN 12 INCHES, DINCH REVIS
     1ED TO*,G15.7,1X,10(1H*))
  320 FORMAT (*0*,45X,*NOTE: GENERALLY SCALE SHOULD BE > OR = 1.0*)
      END
      SUBROUTINE ARRAY(A,IFMT,IN,IRN,DIML,DIMW)
      INTEGER DIML,DIMW,R,P
      DIMENSION A(DIML,DIMW),IFMT(9),IN(9)
C
C     ---READ REMAINING ARRAYS FROM CARDS OR DISK (AS SPECIFIED IN THE
C        OPTIONS) AND WRITE THEM ON DISK IF SPECIFIED IN THE OPTIONS---
```

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C      ***************
C      ***************                                                  GS2M      2319
       R=5                                                              GS2M      2320
       P=6                                                              GS2M      2321
       READ (R,490) FACT,IVAR,IPRN,IRECS,IRECD                          GS2M      2322
       IK=4*IRECS+2*IVAR+IPRN+1                                         GS2M      2323
       GO TO (90,90,110,110,140,140), IK                                GS2M      2324
   90  DO 100 I=1,DIML                                                  GS2M      2325
       DO 100 J=1,DIMW                                                  GS2M      2326
  100  A(I,J)=FACT                                                      GS2M      2327
       WRITE (P,430) IN,FACT                                            GS2M      2328
       GO TO 160                                                        GS2M      2329
  110  IF (IK.EQ.3) WRITE (P,440) IN                                    GS2M      2330
       DO 130 I=1,DIML                                                  GS2M      2331
       READ (R,*) (A(I,J),J=1,DIMW)                                     GS2M      2332
       DO 120 J=1,DIMW                                                  LKPR3       12
  120  A(I,J)=A(I,J)*FACT                                               GS2M      2334
  130  CONTINUE                                                         GS2M      2335
       IF(IK.NE.3) GO TO 160                                            LKPR3       13
            DO 135 I=1,DIML                                             LKPR3       14
       WRITE (P,IFMT) I,(A(I,J),J=1,DIMW)                               LKPR3       15
  135  CONTINUE                                                         LKPR3       16
       GO TO 160                                                        LKPR3       17
  140  READ (2     ) A                                                  GS2M      2337
       IF (IK.EQ.6) GO TO 160                                           GS2M      2338
       WRITE (P,440) IN                                                 GS2M      2339
       DO 150 I=1,DIML                                                  GS2M      2340
  150  WRITE (P,IFMT) I,(A(I,J),J=1,DIMW)                               GS2M      2341
  160  IF (IRECD.EQ.1) WRITE (2     ) A                                 GS2M      2342
       RETURN                                                           GS2M      2343
  430  FORMAT(1H0,41X,9A4,1H=,G15.7)                                    GS2M      2344
  440  FORMAT(1H1,49X,9A4,/,65X,*MATRIX*,/,50X,36(1H-))                 GS2M      2345
  490  FORMAT(F10.0,4I10)                                               GS2M      2346
  510  FORMAT(20F4.0)                                                   GS2M      2347
       END                                                              GS2M      2348
       BLOCK DATA                                                       GS2M      2349
       INTEGER R,P,PU,DIML,DIMW,CHK,WATER,CONVRT,EVAP,CHCK,PNCH,NUM,HEAD, GS2M    2350
     1 CONTR,LEAK,RECH,SIP,ADI,XLABEL,YLABEL                            GS2M      2351
       COMMON /SARRAY/ VF4(11),CHK(15),IH                               GS2M      2352
       COMMON /SPARAM/ WATER,CONVRT,EVAP,CHCK,PNCH,NUM,HEAD,CONTR,EROR,LE GS2M    2353
     1AK,RECH,SIP,U,SS,TT,TMIN,ETDIST,QIT,ERR,TMAX,CDLT,HMAX,YDIM,WIDTH, GS2M     2354
     2NUMS,LSOT,ADI,DELT,SUM,SUMP,SUBS,STORE,TEST,ETGB,ETQD,FACTX,FACTY, GS2M     2355
     3IERR,KOUNT,IFINAL,NUMTIKT,KP,NPER,KTH,ITMAX,LENGTH,NWEL,NW,DIML,DI GS2M     2356
     4MW,JNO1,INO1,R,P,PU,I,J,IDK1,IDK2,LKPR                            GS2M      2357
       COMMON /PR/ XLABEL(3),YLABEL(6),TITLE(5),XN1,MESUR,PRNT(122),BLANK LKPR      39
     1(60),DIGIT(122),VF1(6),VF2(6),VF3(7),XSCALE,DINCH,SYM(17),SN(100), GS2M     2359
     2YN(13),NA(4),N1,N2,N3,YSCALE,FACT1,FACT2                          GS2M      2360
       DATA CHK/10HPUNC      ,10HWATE      ,10HCONT      ,10HNUME      , GS2M      2361
     1 10HCHEC      ,10HEVAP      ,10HCONV      ,10HHEAD      ,         GS2M      2362
     2 10HLEAK      ,10HRECH      ,10HSIP       ,10HLSOR      ,         GS2M      2363
     3 10HADI       ,10HDK1       ,10HDK2       /,R,P,PU/5,6,7/         GS2M      2364
       DATA SYM/1H1,1H2,1H3,1H4,1H5,1H6,1H7,1H8,1H9,1H0,1H$,1H%,1H-,1H+,1 GS2M    2365
     1H ,1HR,1HW/                                                       GS2M      2366
       DATA PRNT/122*1H /,N1,N2,N3,XN1/6,10,133,.833333333E-1/,BLANK/60*1 GS2M    2367
     1H /,NA(4)/1000/                                                   GS2M      2368
       DATA XLABEL/8H X DIS- ,8HTANCE IN,8H  MILES /,YLABEL/8HDISTANCE,8H GS2M    2369
     1 FROM OR,8HIGIN IN ,8HY DIRECT,8HION. IN ,8HMILES   /,TITLE/8HPLOT GS2M     2370
     3 OF ,8HDRAWDOWN,8HPLOT OF ,8HHYDRAULI,8HC HEAD  /                 GS2M      2371
       DATA DIGIT/1H1,1H2,1H3,1H4,1H5,1H6,1H7,1H8,1H9,2H10,2H11,2H12,   GS2M      2372
     12H13,2H14,2H15,2H16,2H17,2H18,2H19,2H20,2H21,2H22,2H23,2H24,2H25, GS2M      2373
     22H26,2H27,2H28,2H29,2H30,2H31,2H32,2H33,2H34,2H35,2H36,2H37,2H38, GS2M      2374
     32H39,2H40,2H41,2H42,2H43,2H44,2H45,2H46,2H47,2H48,2H49,2H50,2H51, GS2M      2375
     42H52,2H53,2H54,2H55,2H56,2H57,2H58,2H59,2H60,2H61,2H62,2H63,2H64, GS2M      2376
     52H65,2H66,2H67,2H68,2H69,2H70,2H71,2H72,2H73,2H74,2H75,2H76,2H77, GS2M      2377
     62H78,2H79,2H80,2H81,2H82,2H83,2H84,2H85,2H86,2H87,2H88,2H89,2H90, GS2M      2378
     72H91,2H92,2H93,2H94,2H95,2H96,2H97,2H98,2H99,3H100,3H101,3H102,   GS2M      2379
                                                                        GS2M      2380
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83H103,3H104,3H105,3H106,3H107,3H108,3H109,3H110,3H111,3H112,3H113,
93H114,3H115,3H116,3H117,3H118,3H119,3H120,3H121,3H122/               GS2M      2381
 DATA VF1/4H(1H ,1H,,4H     ,4HA1,F,4H10.2,1H)/                        GS2M      2382
 DATA VF2/4H(1H ,1H,,4H     ,4HA1,1,4HX,A8,1H)/                        GS2M      2383
 DATA VF3/4H(1H0,1H,,4H     ,4HA1,F,4H3.1,,4H12F1,4H0.2)/              GS2M      2384
 DATA VF4/4H(1H0,1H,,4H     ,4HX,I2,4H,2X,,4H20F6,4H.2/(,4H    ,4HX,  GS2M      2385
120,4HF6.2,2H))/                                                       GS2M      2386
 END                                                                   GS2M      2387
                                                                       GS2M .    2388
```

D.2 Input Data For Lockport Dolomite Model

```
                                                    ***** LOVE CANAL SIMULATIONS --
LOCKPORT DOLOMITE *****       STEADY STATE RUN 1
     LEAK                  LSOR CHEC                          HEAD     1
        23        21         0         1
0
         1         1       0.1       0.1       0.0       0.0       0.0         1
       1.0       1.0       1.0
0
0
0
       1.0         1         0         0         0
21*0/0.580,19*0/0,620,2*640,620,16*0/0,620,2*640,620,16*0/0,555,19*0/0,556,19*0
0,557,19*0/0,558,19*0/0,558,19*0/0,559,19*0/0,559,19*0/0,560,19*0/0,560,19*0
0,561,19*0/0,561,19*0/0,562,19*0/0,562,19*0/0,563,19*0
2*0,2*563,17*0/4*0,4*563,4*564,9*0/12*0,2*564,7*0
14*0,6*564,0/21*0
      -1.0         1         0         0         0
21*0/0,1,19*0/0,4*1,16*0/0,4*1,16*0/0,1,19*0/0,1,19*0/0,1,19*0/0,1,19*0
0,1,19*0/0,1,19*0/0,1,19*0/0,1,19*0/0,1,19*0/0,1,19*0/0,1,19*0/0,1,19*0
0,1,19*0/0,1,19*0/2*0,2*1,17*0/4*0,8*1,9*0
12*0,2*1,7*0/14*0,6*1,0/21*0
    4.92E-4        1
21*0/0,19*1,0/0,19*1,0/0,19*1,0/0,19*1,0/0,19*1,0/0,19*1,0/0,19*1,0
0,19*1,0/0,19*1,0
0,19*10,0/0,19*10,0/0,19*10,0/0,19*10,0/0,19*10,0/0,19*10,0
0,19*10,0/0,19*10,0/2*0,18*10,0/4*0,16*10,0/12*0,8*10,0
14*0,6*10,0/21*0
   1.0E-10         1
21*32.8/21*32.8/21*32.8/21*32.8/21*32.8
21*3.28/21*3.28/21*3.28/21*3.28/21*3.28
21*3.28/21*3.28/21*3.28/21*3.28/21*3.28
21*3.28/21*3.28/21*3.28/21*3.28/21*3.28
21*3.28/21*3.28/21*3.28
       1.0         1
21*0/0,600,2*610,5*620,4*630,2*640,630,4*620,0
0,620,2*640,16*620,0/0,620,2*640,16*620,0/0,2*590,600,3*610,620,12*610,0
0,2*580,17*590,0/0,570,2*580,16*570,0/0,2*570,580,9*565,3*570,4*565,0
0,2*565,570,16*565,0/0,19*565,0/0,19*565,0/0,19*565,0/0,19*565,0/0,19*565,0
0,19*565,0/0,19*565,0/0,19*565,0/0,19*565,0/2*0,5*565,0,12*565,0
4*0,2*565,3*0,11*565,0/12*0,8*565,0/14*0,6*565,0/21*0
       25.         0
     5280.         1
       0.1       0.6       0.6       0.6       0.5       0.4       0.3       0.2
      0.15       0.1       0.1       0.1      0.15       0.2       0.3       0.4
       0.6       0.9       0.9       0.9       0.1
     5280.         1
       0.1       0.9       0.9       0.9       0.9       0.9       0.6       0.4
       0.3       0.2      0.15       0.1       0.1       0.1       0.1       0.1
       0.1       0.1       0.1      0.15       0.2       0.3       0.1
       0.0
         1         0         0       1.0         1       1.0       24.
   -1
```

D.3 Output From Lockport Dolomite Model

```
                                              U. S. G. S.

                                         FINITE-DIFFERENCE MODEL
                                                  FOR
                                     SIMULATION OF GROUND-WATER FLOW

                                             JANUARY, 1975
************************************************************************************************************************************

                                   ***** LOVE CANAL SIMULATIONS --LOCKPORT DOLOMITE *****     STEADY STATE RUN 1
************************************************************************************************************************************

SIMULATION OPTIONS:          LEAK                                   LSOR    CHEC                                   HEAD
       PRINT OUT GRID BLOCK FLUX EVERY    1  TIME STEPS


                                                                  NUMBER OF ROWS =    23
                                                               NUMBER OF COLUMNS =    21
        NUMBER OF WELLS FOR WHICH DRAWDOWN IS COMPUTED AT A SPECIFIED RADIUS =     0
                                            MAXIMUM PERMITTED NUMBER OF ITERATIONS =     1

                                                          WORDS OF Y VECTOR USED =   7944

                                                       NUMBER OF PUMPING PERIODS =     1
                                                    TIME STEPS BETWEEN PRINTOUTS =     1

                                                   ERROR CRITERION FOR CLOSURE =    .1000000
                                                  STEADY STATE ERROR CRITERION =    .1000000

                                             SPECIFIC STORAGE OF CONFINING BED =  0.
                                                      EVAPOTRANSPIRATION RATE =  0.
                                                         EFFECTIVE DEPTH OF ET =   1.000000

                       MULTIPLICATION FACTOR FOR TRANSMISSIVITY IN X DIRECTION =   1.000000
                                                                IN Y DIRECTION =   1.000000
```

STARTING HEAD MATRIX

```
 1      0.0    0.0    0.0    0.0    0.0    0.0    0.0    0.0    0.0    0.0    0.0    0.0    0.0    0.0    0.0    0.0    0.0    0.0    0.0    0.0
        0.0
 2      0.0  580.0    0.0    0.0    0.0    0.0    0.0    0.0    0.0    0.0    0.0    0.0    0.0    0.0    0.0    0.0    0.0    0.0    0.0    0.0
        0.0
 3      0.0  620.0  640.0  640.0  620.0    0.0    0.0    0.0    0.0    0.0    0.0    0.0    0.0    0.0    0.0    0.0    0.0    0.0    0.0    0.0
        0.0
 4      0.0  620.0  640.0  640.0  620.0    0.0    0.0    0.0    0.0    0.0    0.0    0.0    0.0    0.0    0.0    0.0    0.0    0.0    0.0    0.0
        0.0
 5      0.0  555.0    0.0    0.0    0.0    0.0    0.0    0.0    0.0    0.0    0.0    0.0    0.0    0.0    0.0    0.0    0.0    0.0    0.0    0.0
        0.0
 6      0.0  556.0    0.0    0.0    0.0    0.0    0.0    0.0    0.0    0.0    0.0    0.0    0.0    0.0    0.0    0.0    0.0    0.0    0.0    0.0
        0.0
 7      0.0  557.0    0.0    0.0    0.0    0.0    0.0    0.0    0.0    0.0    0.0    0.0    0.0    0.0    0.0    0.0    0.0    0.0    0.0    0.0
        0.0
 8      0.0  558.0    0.0    0.0    0.0    0.0    0.0    0.0    0.0    0.0    0.0    0.0    0.0    0.0    0.0    0.0    0.0    0.0    0.0    0.0
        0.0
 9      0.0  558.0    0.0    0.0    0.0    0.0    0.0    0.0    0.0    0.0    0.0    0.0    0.0    0.0    0.0    0.0    0.0    0.0    0.0    0.0
        0.0
10      0.0  559.0    0.0    0.0    0.0    0.0    0.0    0.0    0.0    0.0    0.0    0.0    0.0    0.0    0.0    0.0    0.0    0.0    0.0    0.0
        0.0
11      0.0  559.0    0.0    0.0    0.0    0.0    0.0    0.0    0.0    0.0    0.0    0.0    0.0    0.0    0.0    0.0    0.0    0.0    0.0    0.0
        0.0
12      0.0  560.0    0.0    0.0    0.0    0.0    0.0    0.0    0.0    0.0    0.0    0.0    0.0    0.0    0.0    0.0    0.0    0.0    0.0    0.0
        0.0
13      0.0  560.0    0.0    0.0    0.0    0.0    0.0    0.0    0.0    0.0    0.0    0.0    0.0    0.0    0.0    0.0    0.0    0.0    0.0    0.0
        0.0
14      0.0  561.0    0.0    0.0    0.0    0.0    0.0    0.0    0.0    0.0    0.0    0.0    0.0    0.0    0.0    0.0    0.0    0.0    0.0    0.0
        0.0
15      0.0  561.0    0.0    0.0    0.0    0.0    0.0    0.0    0.0    0.0    0.0    0.0    0.0    0.0    0.0    0.0    0.0    0.0    0.0    0.0
        0.0
16      0.0  562.0    0.0    0.0    0.0    0.0    0.0    0.0    0.0    0.0    0.0    0.0    0.0    0.0    0.0    0.0    0.0    0.0    0.0    0.0
        0.0
17      0.0  562.0    0.0    0.0    0.0    0.0    0.0    0.0    0.0    0.0    0.0    0.0    0.0    0.0    0.0    0.0    0.0    0.0    0.0    0.0
        0.0
18      0.0  563.0    0.0    0.0    0.0    0.0    0.0    0.0    0.0    0.0    0.0    0.0    0.0    0.0    0.0    0.0    0.0    0.0    0.0    0.0
        0.0
19      0.0    0.0  563.0  563.0    0.0    0.0    0.0    0.0    0.0    0.0    0.0    0.0    0.0    0.0    0.0    0.0    0.0    0.0    0.0    0.0
        0.0
20      0.0    0.0    0.0    0.0  563.0  563.0  563.0  563.0  564.0  564.0  564.0  564.0    0.0    0.0    0.0    0.0    0.0    0.0    0.0    0.0
        0.0
21      0.0    0.0    0.0    0.0    0.0    0.0    0.0    0.0    0.0    0.0    0.0    0.0  564.0  564.0    0.0    0.0    0.0    0.0    0.0    0.0
```

```
       0.0
22     0.0   0.0   0.0   0.0   0.0   0.0   0.0   0.0   0.0   0.0   0.0   0.0   0.0   0.0 564.0 564.0 564.0 564.0 564.0 564.0
       0.0
23     0.0   0.0   0.0   0.0   0.0   0.0   0.0   0.0   0.0   0.0   0.0   0.0   0.0   0.0   0.0   0.0   0.0   0.0   0.0   0.0
       0.0
```

```
                                           STORAGE COEFFICIENT
                                                 MATRIX
                                   ------------------------------------
  1  0.00000  0.00000  0.00000  0.00000  0.00000  0.00000  0.00000
     0.00000  0.00000  0.00000  0.00000  0.00000  0.00000  0.00000  0.00000  0.00000  0.00000  0.00000  0.00000  0.00000  0.00000

  2  0.00000 -1.00000  0.00000  0.00000  0.00000  0.00000  0.00000
     0.00000  0.00000  0.00000  0.00000  0.00000  0.00000  0.00000  0.00000  0.00000  0.00000  0.00000  0.00000  0.00000  0.00000

  3  0.00000 -1.00000 -1.00000 -1.00000 -1.00000  0.00000  0.00000
     0.00000  0.00000  0.00000  0.00000  0.00000  0.00000  0.00000  0.00000  0.00000  0.00000  0.00000  0.00000  0.00000  0.00000

  4  0.00000 -1.00000 -1.00000 -1.00000 -1.00000  0.00000  0.00000
     0.00000  0.00000  0.00000  0.00000  0.00000  0.00000  0.00000  0.00000  0.00000  0.00000  0.00000  0.00000  0.00000  0.00000

  5  0.00000 -1.00000  0.00000  0.00000  0.00000  0.00000  0.00000
     0.00000  0.00000  0.00000  0.00000  0.00000  0.00000  0.00000  0.00000  0.00000  0.00000  0.00000  0.00000  0.00000  0.00000

  6  0.00000 -1.00000  0.00000  0.00000  0.00000  0.00000  0.00000
     0.00000  0.00000  0.00000  0.00000  0.00000  0.00000  0.00000  0.00000  0.00000  0.00000  0.00000  0.00000  0.00000  0.00000

  7  0.00000 -1.00000  0.00000  0.00000  0.00000  0.00000  0.00000
     0.00000  0.00000  0.00000  0.00000  0.00000  0.00000  0.00000  0.00000  0.00000  0.00000  0.00000  0.00000  0.00000  0.00000

  8  0.00000 -1.00000  0.00000  0.00000  0.00000  0.00000  0.00000
     0.00000  0.00000  0.00000  0.00000  0.00000  0.00000  0.00000  0.00000  0.00000  0.00000  0.00000  0.00000  0.00000  0.00000

  9  0.00000 -1.00000  0.00000  0.00000  0.00000  0.00000  0.00000
     0.00000  0.00000  0.00000  0.00000  0.00000  0.00000  0.00000  0.00000  0.00000  0.00000  0.00000  0.00000  0.00000  0.00000

 10  0.00000 -1.00000  0.00000  0.00000  0.00000  0.00000  0.00000
     0.00000  0.00000  0.00000  0.00000  0.00000  0.00000  0.00000  0.00000  0.00000  0.00000  0.00000  0.00000  0.00000  0.00000

 11  0.00000 -1.00000  0.00000  0.00000  0.00000  0.00000  0.00000
     0.00000  0.00000  0.00000  0.00000  0.00000  0.00000  0.00000  0.00000  0.00000  0.00000  0.00000  0.00000  0.00000  0.00000

 12  0.00000 -1.00000  0.00000  0.00000  0.00000  0.00000  0.00000
     0.00000  0.00000  0.00000  0.00000  0.00000  0.00000  0.00000  0.00000  0.00000  0.00000  0.00000  0.00000  0.00000  0.00000

 13  0.00000 -1.00000  0.00000  0.00000  0.00000  0.00000  0.00000
     0.00000  0.00000  0.00000  0.00000  0.00000  0.00000  0.00000  0.00000  0.00000  0.00000  0.00000  0.00000  0.00000  0.00000

 14  0.00000 -1.00000  0.00000  0.00000  0.00000  0.00000  0.00000
     0.00000  0.00000  0.00000  0.00000  0.00000  0.00000  0.00000  0.00000  0.00000  0.00000  0.00000  0.00000  0.00000  0.00000

 15  0.00000 -1.00000  0.00000  0.00000  0.00000  0.00000  0.00000
     0.00000  0.00000  0.00000  0.00000  0.00000  0.00000  0.00000  0.00000  0.00000  0.00000  0.00000  0.00000  0.00000  0.00000

 16  0.00000 -1.00000  0.00000  0.00000  0.00000  0.00000  0.00000
     0.00000  0.00000  0.00000  0.00000  0.00000  0.00000  0.00000  0.00000  0.00000  0.00000  0.00000  0.00000  0.00000  0.00000

 17  0.00000 -1.00000  0.00000  0.00000  0.00000  0.00000  0.00000
     0.00000  0.00000  0.00000  0.00000  0.00000  0.00000  0.00000  0.00000  0.00000  0.00000  0.00000  0.00000  0.00000  0.00000

 18  0.00000 -1.00000  0.00000  0.00000  0.00000  0.00000  0.00000
     0.00000  0.00000  0.00000  0.00000  0.00000  0.00000  0.00000  0.00000  0.00000  0.00000  0.00000  0.00000  0.00000  0.00000

 19  0.00000  0.00000 -1.00000 -1.00000  0.00000  0.00000  0.00000
     0.00000  0.00000  0.00000  0.00000  0.00000  0.00000  0.00000  0.00000  0.00000  0.00000  0.00000  0.00000  0.00000  0.00000

 20  0.00000  0.00000  0.00000  0.00000 -1.00000 -1.00000 -1.00000
     0.00000  0.00000  0.00000  0.00000  0.00000  0.00000  0.00000 -1.00000 -1.00000 -1.00000 -1.00000 -1.00000  0.00000  0.00000
```

```
21  0.00000  0.00000  0.00000  0.00000  0.00000  0.00000  0.00000  0.00000  0.00000  0.00000  0.00000  0.00000 -1.00000 -1.00000
    0.00000  0.00000  0.00000  0.00000  0.00000  0.00000  0.00000

22  0.00000  0.00000  0.00000  0.00000  0.00000  0.00000  0.00000  0.00000  0.00000  0.00000  0.00000  0.00000  0.00000  0.00000
   -1.00000 -1.00000 -1.00000 -1.00000 -1.00000 -1.00000  0.00000

23  0.00000  0.00000  0.00000  0.00000  0.00000  0.00000  0.00000  0.00000  0.00000  0.00000  0.00000  0.00000  0.00000  0.00000
    0.00000  0.00000  0.00000  0.00000  0.00000  0.00000  0.00000
```

```
                                        TRANSMISSIVITY
                                            MATRIX
                                 -------------------------------------

  1 0.00000  0.00000  0.00000  0.00000  0.00000  0.00000  0.00000  0.00000  0.00000  0.00000  0.00000  0.00000  0.00000  0.00000
    0.00000  0.00000  0.00000  0.00000  0.00000  0.00000  0.00000

  2 0.00000   .00049   .00049   .00049   .00049   .00049   .00049   .00049   .00049   .00049   .00049   .00049   .00049   .00049
     .00049   .00049   .00049   .00049   .00049   .00049  0.00000

  3 0.00000   .00049   .00049   .00049   .00049   .00049   .00049   .00049   .00049   .00049   .00049   .00049   .00049   .00049
     .00049   .00049   .00049   .00049   .00049   .00049  0.00000

  4 0.00000   .00049   .00049   .00049   .00049   .00049   .00049   .00049   .00049   .00049   .00049   .00049   .00049   .00049
     .00049   .00049   .00049   .00049   .00049   .00049  0.00000

  5 0.00000   .00049   .00049   .00049   .00049   .00049   .00049   .00049   .00049   .00049   .00049   .00049   .00049   .00049
     .00049   .00049   .00049   .00049   .00049   .00049  0.00000

  6 0.00000   .00049   .00049   .00049   .00049   .00049   .00049   .00049   .00049   .00049   .00049   .00049   .00049   .00049
     .00049   .00049   .00049   .00049   .00049   .00049  0.00000

  7 0.00000   .00049   .00049   .00049   .00049   .00049   .00049   .00049   .00049   .00049   .00049   .00049   .00049   .00049
     .00049   .00049   .00049   .00049   .00049   .00049  0.00000

  8 0.00000   .00049   .00049   .00049   .00049   .00049   .00049   .00049   .00049   .00049   .00049   .00049   .00049   .00049
     .00049   .00049   .00049   .00049   .00049   .00049  0.00000

  9 0.00000   .00049   .00049   .00049   .00049   .00049   .00049   .00049   .00049   .00049   .00049   .00049   .00049   .00049
     .00049   .00049   .00049   .00049   .00049   .00049  0.00000

 10 0.00000   .00049   .00049   .00049   .00049   .00049   .00049   .00049   .00049   .00049   .00049   .00049   .00049   .00049
     .00049   .00049   .00049   .00049   .00049   .00049  0.00000

 11 0.00000   .00492   .00492   .00492   .00492   .00492   .00492   .00492   .00492   .00492   .00492   .00492   .00492   .00492
     .00492   .00492   .00492   .00492   .00492   .00492  0.00000

 12 0.00000   .00492   .00492   .00492   .00492   .00492   .00492   .00492   .00492   .00492   .00492   .00492   .00492   .00492
     .00492   .00492   .00492   .00492   .00492   .00492  0.00000

 13 0.00000   .00492   .00492   .00492   .00492   .00492   .00492   .00492   .00492   .00492   .00492   .00492   .00492   .00492
     .00492   .00492   .00492   .00492   .00492   .00492  0.00000

 14 0.00000   .00492   .00492   .00492   .00492   .00492   .00492   .00492   .00492   .00492   .00492   .00492   .00492   .00492
     .00492   .00492   .00492   .00492   .00492   .00492  0.00000

 15 0.00000   .00492   .00492   .00492   .00492   .00492   .00492   .00492   .00492   .00492   .00492   .00492   .00492   .00492
     .00492   .00492   .00492   .00492   .00492   .00492  0.00000

 16 0.00000   .00492   .00492   .00492   .00492   .00492   .00492   .00492   .00492   .00492   .00492   .00492   .00492   .00492
     .00492   .00492   .00492   .00492   .00492   .00492  0.00000

 17 0.00000   .00492   .00492   .00492   .00492   .00492   .00492   .00492   .00492   .00492   .00492   .00492   .00492   .00492
     .00492   .00492   .00492   .00492   .00492   .00492  0.00000

 18 0.00000   .00492   .00492   .00492   .00492   .00492   .00492   .00492   .00492   .00492   .00492   .00492   .00492   .00492
     .00492   .00492   .00492   .00492   .00492   .00492  0.00000

 19 0.00000  0.00000   .00492   .00492   .00492   .00492   .00492   .00492   .00492   .00492   .00492   .00492   .00492   .00492
     .00492   .00492   .00492   .00492   .00492   .00492  0.00000

 20 0.00000  0.00000  0.00000  0.00000   .00492   .00492   .00492   .00492   .00492   .00492   .00492   .00492   .00492   .00492
     .00492   .00492   .00492   .00492   .00492   .00492  0.00000
```

```
21  0.00000  0.00000  0.00000  0.00000  0.00000  0.00000  0.00000  0.00000  0.00000  0.00000  0.00000  0.00000   .00492   .00492
     .00492   .00492   .00492   .00492   .00492   .00492  0.00000
22  0.00000  0.00000  0.00000  0.00000  0.00000  0.00000  0.00000  0.00000  0.00000  0.00000  0.00000  0.00000  0.00000  0.00000
     .00492   .00492   .00492   .00492   .00492   .00492  0.00000
23  0.00000  0.00000  0.00000  0.00000  0.00000  0.00000  0.00000  0.00000  0.00000  0.00000  0.00000  0.00000  0.00000  0.00000
    0.00000  0.00000  0.00000  0.00000  0.00000  0.00000  0.00000
```

```
                                   CONFINING BED HYDRAULIC CONDUCTIVITY
                                                  MATRIX
                                   ------------------------------------

   1   .328E-08  .328E-08  .328E-08  .328E-08  .328E-08  .328E-08  .328E-08  .328E-08  .328E-08  .328E-08
       .328E-08  .328E-08  .328E-08  .328E-08  .328E-08  .328E-08  .328E-08  .328E-08  .328E-08  .328E-08
       .328E-08

   2   .328E-08  .328E-08  .328E-08  .328E-08  .328E-08  .328E-08  .328E-08  .328E-08  .328E-08  .328E-08
       .328E-08  .328E-08  .328E-08  .328E-08  .328E-08  .328E-08  .328E-08  .328E-08  .328E-08  .328E-08
       .328E-08

   3   .328E-08  .328E-08  .328E-08  .328E-08  .328E-08  .328E-08  .328E-08  .328E-08  .328E-08  .328E-08
       .328E-08  .328E-08  .328E-08  .328E-08  .328E-08  .328E-08  .328E-08  .328E-08  .328E-08  .328E-08
       .328E-08

   4   .328E-08  .328E-08  .328E-08  .328E-08  .328E-08  .328E-08  .328E-08  .328E-08  .328E-08  .328E-08
       .328E-08  .328E-08  .328E-08  .328E-08  .328E-08  .328E-08  .328E-08  .328E-08  .328E-08  .328E-08
       .328E-08

   5   .328E-08  .328E-08  .328E-08  .328E-08  .328E-08  .328E-08  .328E-08  .328E-08  .328E-08  .328E-08
       .328E-08  .328E-08  .328E-08  .328E-08  .328E-08  .328E-08  .328E-08  .328E-08  .328E-08  .328E-08
       .328E-08

   6   .328E-09  .328E-09  .328E-09  .328E-09  .328E-09  .328E-09  .328E-09  .328E-09  .328E-09  .328E-09
       .328E-09  .328E-09  .328E-09  .328E-09  .328E-09  .328E-09  .328E-09  .328E-09  .328E-09  .328E-09
       .328E-09

   7   .328E-09  .328E-09  .328E-09  .328E-09  .328E-09  .328E-09  .328E-09  .328E-09  .328E-09  .328E-09
       .328E-09  .328E-09  .328E-09  .328E-09  .328E-09  .328E-09  .328E-09  .328E-09  .328E-09  .328E-09
       .328E-09

   8   .328E-09  .328E-09  .328E-09  .328E-09  .328E-09  .328E-09  .328E-09  .328E-09  .328E-09  .328E-09
       .328E-09  .328E-09  .328E-09  .328E-09  .328E-09  .328E-09  .328E-09  .328E-09  .328E-09  .328E-09
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   9   .328E-09  .328E-09  .328E-09  .328E-09  .328E-09  .328E-09  .328E-09  .328E-09  .328E-09  .328E-09
       .328E-09  .328E-09  .328E-09  .328E-09  .328E-09  .328E-09  .328E-09  .328E-09  .328E-09  .328E-09
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  10   .328E-09  .328E-09  .328E-09  .328E-09  .328E-09  .328E-09  .328E-09  .328E-09  .328E-09  .328E-09
       .328E-09  .328E-09  .328E-09  .328E-09  .328E-09  .328E-09  .328E-09  .328E-09  .328E-09  .328E-09
       .328E-09

  11   .328E-09  .328E-09  .328E-09  .328E-09  .328E-09  .328E-09  .328E-09  .328E-09  .328E-09  .328E-09
       .328E-09  .328E-09  .328E-09  .328E-09  .328E-09  .328E-09  .328E-09  .328E-09  .328E-09  .328E-09
       .328E-09

  12   .328E-09  .328E-09  .328E-09  .328E-09  .328E-09  .328E-09  .328E-09  .328E-09  .328E-09  .328E-09
       .328E-09  .328E-09  .328E-09  .328E-09  .328E-09  .328E-09  .328E-09  .328E-09  .328E-09  .328E-09
       .328E-09

  13   .328E-09  .328E-09  .328E-09  .328E-09  .328E-09  .328E-09  .328E-09  .328E-09  .328E-09  .328E-09
       .328E-09  .328E-09  .328E-09  .328E-09  .328E-09  .328E-09  .328E-09  .328E-09  .328E-09  .328E-09
       .328E-09

  14   .328E-09  .328E-09  .328E-09  .328E-09  .328E-09  .328E-09  .328E-09  .328E-09  .328E-09  .328E-09
       .328E-09  .328E-09  .328E-09  .328E-09  .328E-09  .328E-09  .328E-09  .328E-09  .328E-09  .328E-09
       .328E-09

  15   .328E-09  .328E-09  .328E-09  .328E-09  .328E-09  .328E-09  .328E-09  .328E-09  .328E-09  .328E-09
       .328E-09  .328E-09  .328E-09  .328E-09  .328E-09  .328E-09  .328E-09  .328E-09  .328E-09  .328E-09
       .328E-09
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16   .328E-09   .328E-09   .328E-09   .328E-09   .328E-09   .328E-09   .328E-09   .328E-09   .328E-09   .328E-09
     .328E-09   .328E-09   .328E-09   .328E-09   .328E-09   .328E-09   .328E-09   .328E-09   .328E-09   .328E-09
     .328E-09

17   .328E-09   .328E-09   .328E-09   .328E-09   .328E-09   .328E-09   .328E-09   .328E-09   .328E-09   .328E-09
     .328E-09   .328E-09   .328E-09   .328E-09   .328E-09   .328E-09   .328E-09   .328E-09   .328E-09   .328E-09
     .328E-09

18   .328E-09   .328E-09   .328E-09   .328E-09   .328E-09   .328E-09   .328E-09   .328E-09   .328E-09   .328E-09
     .328E-09   .328E-09   .328E-09   .328E-09   .328E-09   .328E-09   .328E-09   .328E-09   .328E-09   .328E-09
     .328E-09

19   .328E-09   .328E-09   .328E-09   .328E-09   .328E-09   .328E-09   .328E-09   .328E-09   .328E-09   .328E-09
     .328E-09   .328E-09   .328E-09   .328E-09   .328E-09   .328E-09   .328E-09   .328E-09   .328E-09   .328E-09
     .328E-09

20   .328E-09   .328E-09   .328E-09   .328E-09   .328E-09   .328E-09   .328E-09   .328E-09   .328E-09   .328E-09
     .328E-09   .328E-09   .328E-09   .328E-09   .328E-09   .328E-09   .328E-09   .328E-09   .328E-09   .328E-09
     .328E-09

21   .328E-09   .328E-09   .328E-09   .328E-09   .328E-09   .328E-09   .328E-09   .328E-09   .328E-09   .328E-09
     .328E-09   .328E-09   .328E-09   .328E-09   .328E-09   .328E-09   .328E-09   .328E-09   .328E-09   .328E-09
     .328E-09

22   .328E-09   .328E-09   .328E-09   .328E-09   .328E-09   .328E-09   .328E-09   .328E-09   .328E-09   .328E-09
     .328E-09   .328E-09   .328E-09   .328E-09   .328E-09   .328E-09   .328E-09   .328E-09   .328E-09   .328E-09
     .328E-09

23   .328E-09   .328E-09   .328E-09   .328E-09   .328E-09   .328E-09   .328E-09   .328E-09   .328E-09   .328E-09
     .328E-09   .328E-09   .328E-09   .328E-09   .328E-09   .328E-09   .328E-09   .328E-09   .328E-09   .328E-09
     .328E-09
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                                        RIVER HEAD
                                          MATRIX
                                 ------------------------------------

  1      0.0   0.0   0.0   0.0   0.0   0.0   0.0   0.0   0.0   0.0   0.0   0.0   0.0   0.0   0.0   0.0   0.0   0.0   0.0   0.0
         0.0

  2      0.0 600.0 610.0 610.0 620.0 620.0 620.0 620.0 620.0 630.0 630.0 630.0 630.0 640.0 640.0 630.0 620.0 620.0 620.0 620.0
         0.0

  3      0.0 620.0 640.0 640.0 620.0 620.0 620.0 620.0 620.0 620.0 620.0 620.0 620.0 620.0 620.0 620.0 620.0 620.0 620.0 620.0
         0.0

  4      0.0 620.0 640.0 640.0 620.0 620.0 620.0 620.0 620.0 620.0 620.0 620.0 620.0 620.0 620.0 620.0 620.0 620.0 620.0 620.0
         0.0

  5      0.0 590.0 590.0 600.0 610.0 610.0 610.0 620.0 610.0 610.0 610.0 610.0 610.0 610.0 610.0 610.0 610.0 610.0 610.0 610.0
         0.0

  6      0.0 580.0 580.0 590.0 590.0 590.0 590.0 590.0 590.0 590.0 590.0 590.0 590.0 590.0 590.0 590.0 590.0 590.0 590.0 590.0
         0.0

  7      0.0 570.0 580.0 580.0 570.0 570.0 570.0 570.0 570.0 570.0 570.0 570.0 570.0 570.0 570.0 570.0 570.0 570.0 570.0 570.0
         0.0

  8      0.0 570.0 570.0 580.0 565.0 565.0 565.0 565.0 565.0 565.0 565.0 565.0 565.0 570.0 570.0 570.0 565.0 565.0 565.0 565.0
         0.0

  9      0.0 565.0 565.0 570.0 565.0 565.0 565.0 565.0 565.0 565.0 565.0 565.0 565.0 565.0 565.0 565.0 565.0 565.0 565.0 565.0
         0.0

 10      0.0 565.0 565.0 565.0 565.0 565.0 565.0 565.0 565.0 565.0 565.0 565.0 565.0 565.0 565.0 565.0 565.0 565.0 565.0 565.0
         0.0

 11      0.0 565.0 565.0 565.0 565.0 565.0 565.0 565.0 565.0 565.0 565.0 565.0 565.0 565.0 565.0 565.0 565.0 565.0 565.0 565.0
         0.0

 12      0.0 565.0 565.0 565.0 565.0 565.0 565.0 565.0 565.0 565.0 565.0 565.0 565.0 565.0 565.0 565.0 565.0 565.0 565.0 565.0
         0.0

 13      0.0 565.0 565.0 565.0 565.0 565.0 565.0 565.0 565.0 565.0 565.0 565.0 565.0 565.0 565.0 565.0 565.0 565.0 565.0 565.0
         0.0

 14      0.0 565.0 565.0 565.0 565.0 565.0 565.0 565.0 565.0 565.0 565.0 565.0 565.0 565.0 565.0 565.0 565.0 565.0 565.0 565.0
         0.0

 15      0.0 565.0 565.0 565.0 565.0 565.0 565.0 565.0 565.0 565.0 565.0 565.0 565.0 565.0 565.0 565.0 565.0 565.0 565.0 565.0
         0.0

 16      0.0 565.0 565.0 565.0 565.0 565.0 565.0 565.0 565.0 565.0 565.0 565.0 565.0 565.0 565.0 565.0 565.0 565.0 565.0 565.0
         0.0

 17      0.0 565.0 565.0 565.0 565.0 565.0 565.0 565.0 565.0 565.0 565.0 565.0 565.0 565.0 565.0 565.0 565.0 565.0 565.0 565.0
         0.0

 18      0.0 565.0 565.0 565.0 565.0 565.0 565.0 565.0 565.0 565.0 565.0 565.0 565.0 565.0 565.0 565.0 565.0 565.0 565.0 565.0
         0.0

 19      0.0   0.0 565.0 565.0 565.0 565.0 565.0   0.0 565.0 565.0 565.0 565.0 565.0 565.0 565.0 565.0 565.0 565.0 565.0 565.0
         0.0

 20      0.0   0.0   0.0   0.0 565.0 565.0   0.0   0.0   0.0 565.0 565.0 565.0 565.0 565.0 565.0 565.0 565.0 565.0 565.0 565.0
         0.0
 21     0.0    0.0    0.0    0.0    0.0    0.0    0.0    0.0    0.0    0.0    0.0    0.0  565.0  565.0  565.0  565.0  565.0  565.0  565.0  565.0
        0.0
 22     0.0    0.0    0.0    0.0    0.0    0.0    0.0    0.0    0.0    0.0    0.0    0.0    0.0    0.0  565.0  565.0  565.0  565.0  565.0  565.0
        0.0
 23     0.0    0.0    0.0    0.0    0.0    0.0    0.0    0.0    0.0    0.0    0.0    0.0    0.0    0.0    0.0    0.0    0.0    0.0    0.0    0.0
        0.0

                                     CONFINING BED THICKNESS      =   25.00000
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                                   GRID SPACING IN PROTOTYPE IN X DIRECTION
                                   ----------------------------------------
                                                                                                .
  528.      3168.     3168.     3168.     3168.     2112.     1584.     1056.      792.      528.      528.      528.

  792.      1056.     1584.     2112.     3168.     4752.     4752.     4752.      528.

                                   GRID SPACING IN PROTOTYPE IN Y DIRECTION
                                   ----------------------------------------

  528.      4752.     4752.     4752.     4752.     4752.     3168.     2112.     1584.     1056.      792.      528.

  528.       528.      528.      528.      528.      528.      528.      792.     1056.     1584.      528.

                              SOLUTION BY LDU FACTORIZATION ASSUMING D4 ORDERING
                              ##################################################

                                             BETA = 1.00

                                  ITERATIONS:  MINIMUM =    1
                                               MAXIMUM =    1
                                                 THETA = 0.00

                       !!!!!WARNING!!!!!MINIMUM DIMENSIONS FOR ARRAYS USED BY THIS METHOD ARE AS FOLLOWS:

                                                  AU:  165 BY    5
                                                  AL:  165 BY   19
                                                  IC:  165 BY    5
                                                   B:  330
                                                  IN:   21 BY   19

                                    PUMPING PERIOD NO.   1:      1.00 DAYS
                                    --------------------------------------

                                      NUMBER OF TIME STEPS=     1

                                            DELT IN HOURS =    24.000

                                      MULTIPLIER FOR DELT =     1.000

                                                     0 WELLS
                                                    ---------

                                   I         J     PUMPING RATE  WELL RADIUS

       ROW     2
                   CONSTANT HEAD FLUX RATES ...'LLL/T
-.203E-01 0.        0.        0.        0.        0.        0.        0.        0.        0.        0.        0.
0.        0.        0.        0.        0.        0.        0.
                   LEAKAGE RATES ... LLL/T
0.         .495E-02 -.760E-02  .225E-02 -.112E-03 -.103E-02 -.158E-02 -.201E-02  .134E-02  .936E-03  .572E-03  .199E-03
 .548E-02  .771E-02  .226E-02 -.395E-02 -.739E-03 -.196E-04  .632E-04

       ROW     3
                   CONSTANT HEAD FLUX RATES ... LLL/T
0.         .107E-01  .858E-02  .389E-03 0.        0.        0.        0.        0.        0.        0.        0.
```

```
0.         0.         0.         0.         0.         0.         0.
                  LEAKAGE RATES ... LLL/T
0.         0.         0.         0.         .235E-04 -.103E-03 -.184E-03 -.220E-03 -.190E-03 -.225E-03 -.258E-03 -.443E-03
-.671E-03 -.104E-02 -.103E-02 -.403E-03  .311E-03  .499E-03  .526E-03

      ROW    4
                  CONSTANT HEAD FLUX RATES ... LLL/T
0.          .170E-01  .128E-01  .508E-02 0.         0.         0.         0.         0.         0.         0.         0.
0.         0.         0.         0.         0.         0.         0.
                  LEAKAGE RATES ... LLL/T
0.         0.         0.         0.          .133E-02  .114E-02  .759E-03  .582E-03  .394E-03  .398E-03  .401E-03  .607E-03
 .818E-03  .124E-02  .170E-02  .268E-02  .415E-02  .418E-02  .419E-02

      ROW    5
                  CONSTANT HEAD FLUX RATES ... LLL/T
-.246E-01 0.         0.         0.         0.         0.         0.         0.         0.         0.         0.         0.
0.         0.         0.         0.         0.         0.         0.
                  LEAKAGE RATES ... LLL/T
0.          .338E-02 -.201E-02  .546E-02  .179E-02  .371E-03  .594E-02 -.471E-04  .993E-04  .175E-03  .230E-03  .420E-03
 .645E-03  .106E-02  .148E-02  .227E-02  .344E-02  .344E-02  .344E-02

      ROW    6
                  CONSTANT HEAD FLUX RATES ... LLL/T
-.122E-01 0.         0.         0.         0.         0.         0.         0.         0.         0.         0.         0.
0.         0.         0.         0.         0.         0.         0.
                  LEAKAGE RATES ... LLL/T
0.          .147E-02  .142E-02  .390E-03 -.150E-04 -.101E-03 -.963E-04 -.812E-04 -.571E-04 -.591E-04 -.606E-04 -.933E-04
-.128E-03 -.197E-03 -.269E-03 -.409E-03 -.619E-03 -.620E-03 -.621E-03

      ROW    7
                  CONSTANT HEAD FLUX RATES ... LLL/T
-.512E-02 0.         0.         0.         0.         0.         0.         0.         0.         0.         0.         0.
0.         0.         0.         0.         0.         0.         0.
                  LEAKAGE RATES ... LLL/T
0.          .166E-02  .844E-03 -.802E-03 -.647E-03 -.526E-03 -.365E-03 -.280E-03 -.189E-03 -.191E-03 -.193E-03 -.292E-03
-.393E-03 -.598E-03 -.804E-03 -.121E-02 -.181E-02 -.182E-02 -.182E-02

      ROW    8
                  CONSTANT HEAD FLUX RATES ... LLL/T
-.219E-02 0.         0.         0.         0.         0.         0.         0.         0.         0.         0.         0.
0.         0.         0.         0.         0.         0.         0.
                  LEAKAGE RATES ... LLL/T
0.          .468E-03  .959E-03 -.466E-03 -.357E-03 -.286E-03 -.198E-03 -.152E-03 -.103E-03 -.104E-03 -.106E-03 -.161E-03
-.739E-04 -.118E-03 -.153E-03 -.671E-03 -.100E-02 -.101E-02 -.101E-02

      ROW    9
                  CONSTANT HEAD FLUX RATES ... LLL/T
-.125E-02 0.         0.         0.         0.         0.         0.         0.         0.         0.         0.         0.
0.         0.         0.         0.         0.         0.         0.
                  LEAKAGE RATES ... LLL/T
0.          .125E-03  .253E-03 -.127E-03 -.108E-03 -.914E-04 -.654E-04 -.513E-04 -.352E-04 -.360E-04 -.368E-04 -.566E-04
-.779E-04 -.121E-03 -.166E-03 -.250E-03 -.379E-03 -.381E-03 -.382E-03

      ROW   10
                  CONSTANT HEAD FLUX RATES ... LLL/T
-.544E-03 0.         0.         0.         0.         0.         0.         0.         0.         0.         0.         0.
0.         0.         0.         0.         0.         0.         0.
                  LEAKAGE RATES ... LLL/T
0.          .118E-03  .438E-04  .144E-04 -.117E-05 -.606E-05 -.656E-05 -.625E-05 -.479E-05 -.527E-05 -.574E-05 -.944E-05
-.140E-04 -.236E-04 -.348E-04 -.558E-04 -.880E-04 -.901E-04 -.908E-04

      ROW   11
                  CONSTANT HEAD FLUX RATES ... LLL/T
-.374E-02 0.         0.         0.         0.         0.         0.         0.         0.         0.         0.         0.
0.         0.         0.         0.         0.         0.         0.
                  LEAKAGE RATES ... LLL/T
 0.        .974E-04  .597E-04  .424E-04  .219E-04  .131E-04  .695E-05
 .145E-05  .301E-06 -.221E-05 -.680E-05 -.141E-04 -.158E-04 -.164E-04  .424E-05  .236E-05  .200E-05  .165E-05  .187E-05

      ROW   12
                CONSTANT HEAD FLUX RATES ... LLL/T
-.172E-02 0.        0.        0.        0.        0.        0.
 0.       0.        0.        0.        0.        0.        0.        0.        0.        0.        0.        0.
                LEAKAGE RATES ... LLL/T
 0.        .636E-04  .412E-04  .305E-04  .164E-04  .102E-04  .559E-05
 .184E-05  .151E-05  .292E-06 -.190E-05 -.543E-05 -.656E-05 -.693E-05  .352E-05  .203E-05  .178E-05  .154E-05  .190E-05

      ROW   13
                CONSTANT HEAD FLUX RATES ... LLL/T
-.179E-02 0.        0.        0.        0.        0.        0.
 0.       0.        0.        0.        0.        0.        0.        0.        0.        0.        0.        0.
                LEAKAGE RATES ... LLL/T
 0.        .619E-04  .421E-04  .323E-04  .178E-04  .113E-04  .637E-05
 .251E-05  .252E-05  .166E-05  .175E-06 -.228E-05 -.339E-05 -.375E-05  .407E-05  .238E-05  .212E-05  .188E-05  .240E-05

      ROW   14
                CONSTANT HEAD FLUX RATES ... LLL/T
-.106E-02 0.        0.        0.        0.        0.        0.
 0.       0.        0.        0.        0.        0.        0.        0.        0.        0.        0.        0.
                LEAKAGE RATES ... LLL/T
 0.        .594E-04  .427E-04  .340E-04  .193E-04  .126E-04  .718E-05
 .315E-05  .349E-05  .298E-05  .220E-05  .836E-06 -.231E-06 -.579E-06  .462E-05  .273E-05  .246E-05  .221F-05  .288E-05

      ROW   15
                CONSTANT HEAD FLUX RATES ... LLL/T
-.116E-02 0.        0.        0.        0.        0.        0.
 0.       0.        0.        0.        0.        0.        0.        0.        0.        0.        0.        0.
                LEAKAGE RATES ... LLL/T
 0.        .567E-04  .431E-04  .356E-04  .208E-04  .139E-04  .806E-05
 .375E-05  .442E-05  .425E-05  .420E-05  .393E-05  .292E-05  .259E-05  .518E-05  .306E-05  .277E-05  .251E-05  .333E-05

      ROW   16
                CONSTANT HEAD FLUX RATES ... LLL/T
-.458E-03 0.        0.        0.        0.        0.        0.
 0.       0.        0.        0.        0.        0.        0.        0.        0.        0.        0.        0.
                LEAKAGE RATES ... LLL/T
 0.        .536E-04  .433E-04  .372E-04  .224E-04  .153E-04  .902E-05
 .432E-05  .530E-05  .549E-05  .616E-05  .701E-05  .606E-05  .575E-05  .572E-05  .337E-05  .306E-05  .279E-05  .375E-05

      ROW   17
                CONSTANT HEAD FLUX RATES ... LLL/T
-.576E-03 0.        0.        0.        0.        0.        0.
 0.       0.        0.        0.        0.        0.        0.        0.        0.        0.        0.        0.
                LEAKAGE RATES ... LLL/T
 0.        .504E-04  .435E-04  .388E-04  .239E-04  .168E-04  .102E-04
 .486E-05  .615E-05  .669E-05  .808E-05  .101E-04  .920E-05  .891E-05  .622E-05  .363E-05  .330E-05  .304E-05  .413E-05

      ROW   18
                CONSTANT HEAD FLUX RATES ... LLL/T
 .118E-03 0.        0.        0.        0.        0.        0.
 0.       0.        0.        0.        0.        0.        0.        0.        0.        0.        0.        0.
                LEAKAGE RATES ... LLL/T
 0.        .470E-04  .437E-04  .403E-04  .256E-04  .184E-04  .116E-04
 .536E-05  .695E-05  .785E-05  .998E-05  .131E-04  .123E-04  .121E-04  .660E-05  .381E-05  .349E-05  .325E-05  .448E-05

      ROW   19
                CONSTANT HEAD FLUX RATES ... LLL/T
 0.        .424E-02 -.336E-03 0.        0.        0.        0.
 0.       0.        0.        0.        0.        0.        0.        0.        0.        0.        0.        0.
                LEAKAGE RATES ... LLL/T
 0.       0.        0.        .419E-04  .272E-04  .200E-04 -.412E-02
 .584E-05  .772E-05  .897E-05  .119E-04  .162E-04  .155E-04  .153E-04  .664E-05  .386E-05  .360E-05  .342E-05  .479E-05
```

```
      RUN   20
                CONSTANT HEAD FLUX RATES ... LLL/T
0.        0.        0.        -.213E-02 -.223E-02 -.207E-02 -.861E-03  .124E-02  .214E-03 -.573E-04 -.620E-03 0.
0.        0.        0.        0.        0.        0.        0.
                LEAKAGE RATES ... LLL/T
0.        0.        0.        0.        0.        0.        0.        0.        0.        0.        0.          .771E-05
 .965E-05  .129E-04  .155E-04  .213E-04  .299E-04  .291E-04  .288E-04

      RUN   21
                CONSTANT HEAD FLUX RATES ... LLL/T
0.        0.        0.        0.        0.        0.        0.        0.        0.        0.        0.         -.264E-03
-.111E-02 0.        0.        0.        0.        0.        0.
                LEAKAGE RATES ... LLL/T
0.        0.        0.        0.        0.        0.        0.        0.        0.        0.        0.        0.
0.         .196E-04  .243E-04  .348E-04  .505E-04  .499E-04  .497E-04

      RUN   22
                CONSTANT HEAD FLUX RATES ... LLL/T
0.        0.        0.        0.        0.        0.        0.        0.        0.        0.        0.        0.
0.        -.643E-03 -.133E-02 -.246E-02 -.412E-02 -.429E-02 -.435E-02
                LEAKAGE RATES ... LLL/T
0.        0.        0.        0.        0.        0.        0.        0.        0.        0.        0.        0.
0.        0.        0.        0.        0.        0.        0.
```

```
                    ------------------------------------------------------------
                    &               TIME STEP NUMBER =          1             &
                    ------------------------------------------------------------

                         SIZE OF TIME STEP IN SECONDS=      86400.00

                              TOTAL SIMULATION TIME IN SECONDS=      86400.00
                                                      MINUTES=        1440.00
                                                        HOURS=          24.00
                                                         DAYS=           1.00
                                                        YEARS=            .00

                    DURATION OF CURRENT PUMPING PERIOD IN DAYS=          1.00
                                                        YEARS=            .00

      CUMULATIVE MASS BALANCE:                 L**3                  RATES FOR THIS TIME STEP:                L**3/T
      ------------------------                                       -------------------------

               SOURCES:                                                                STORAGE =            0.0000
               --------                                                               RECHARGE =            0.0000
                     STORAGE =                 0.00                              CONSTANT FLUX =            0.0000
                    RECHARGE =                 0.00                                    PUMPING =            0.0000
               CONSTANT FLUX =                 0.00                         EVAPOTRANSPIRATION =            0.0000
               CONSTANT HEAD =              5207.31                             CONSTANT HEAD:
                     LEAKAGE =              8250.51                                         IN =             .0603
               TOTAL SOURCES =             13457.82                                        OUT =            -.1035
                                                                                      LEAKAGE:
              DISCHARGES:                                            FROM PREVIOUS PUMPING PERIOD =           59.1402
              -----------                                                                TOTAL =             .0433
          EVAPOTRANSPIRATION =                 0.00
               CONSTANT HEAD =              8946.08                               SUM OF RATES =            -.0000
              QUANTITY PUMPED =                0.00
                     LEAKAGE =              4511.74
             TOTAL DISCHARGE =             13457.82

           DISCHARGE-SOURCES =                  .00
          PER CENT DIFFERENCE =                 .00

 MAXIMUM HEAD CHANGE FOR EACH ITERATION:
 --------------------------------------

    632.1965       .0000

 MAXIMUM CHANGE IN HEAD FOR THIS TIME STEP =   632.000
 -------------------------------------------------------

 TIME STEP :  1
 ----------

 ITERATIONS:  1
 ----------
```

```
                                 HEAD MATRIX
                                 -----------

 1    0.00  0.00  0.00  0.00  0.00  0.00  0.00  0.00  0.00  0.00  0.00  0.00  0.00  0.00  0.00  0.00  0.00  0.00  0.00  0.00
      0.00

 2    0.00580.00607.50613.85618.86620.09621.05622.41624.07625.92627.16628.26629.60631.67632.20628.28622.00620.25620.01619.98
      0.00

 3    0.00620.00640.00640.00620.00619.98620.10620.28620.44620.58620.68620.78620.90621.02621.05620.78620.20619.90619.83619.82
      0.00

 4    0.00620.00640.00640.00620.00618.99618.85618.85618.82618.80618.79618.78618.77618.76618.74618.71618.65618.60618.59618.59
      0.00

 5    0.00555.00588.29601.02607.24608.64609.62610.98610.10609.70609.47609.30609.15609.02608.92608.87608.85608.84608.84608.84
      0.00

 6    0.00556.00572.54582.82588.03590.11591.03591.46591.65591.74591.79591.84591.89591.94592.00592.04592.07592.09592.09592.10
      0.00

 7    0.00557.00567.40573.59576.09577.37577.99578.32578.50578.62578.70578.78578.86578.96579.08579.16579.18579.19579.19579.20
      0.00

 8    0.00558.00564.67569.07570.31571.10571.53571.78571.94572.05572.14572.23572.34572.53572.69572.78572.64572.63572.64572.65
      0.00

 9    0.00558.00563.10566.00566.93567.46567.78567.98568.12568.21568.28568.35568.44568.55568.68568.78568.80568.83568.86568.87
      0.00

10    0.00559.00562.32564.00564.67565.04565.28565.45565.57565.65565.72565.78565.86565.96566.07566.19566.27566.34566.37566.38
      0.00

11    0.00559.00562.04563.19563.71564.00564.20564.37564.49564.57564.64564.70564.77564.87564.98565.10565.21565.29565.32565.33
      0.00

12    0.00560.00562.10563.12563.61563.88564.07564.24564.36564.45564.51564.58564.65564.75564.86564.98565.09565.16565.20565.21
      0.00

13    0.00560.00562.18563.08563.53563.78563.97564.13564.26564.35564.42564.49564.56564.66564.77564.89564.99565.07565.10565.11
      0.00

14    0.00561.00562.29563.06563.45563.68563.85564.02564.16564.25564.33564.40564.47564.57564.68564.80564.90564.97565.01565.02
      0.00

15    0.00561.00562.41563.04563.38563.58563.73563.90564.06564.16564.24564.31564.39564.49564.60564.71564.81564.88564.91564.92
      0.00

16    0.00562.00562.56563.02563.31563.47563.61563.77563.96564.08564.16564.24564.32564.41564.52564.62564.72564.79564.82564.83
      0.00

17    0.00562.00562.70563.02563.23563.36563.47563.61563.87564.01564.10564.17564.25564.34564.44564.54564.63564.69564.72564.73
      0.00

18    0.00563.00562.86563.01563.16563.25563.33563.41563.80563.96564.05564.11564.18564.27564.37564.46564.55564.60564.63564.63
      0.00

19    0.00  0.00563.00563.00563.09563.14563.18563.11563.79563.95564.01564.06564.13564.20564.30564.39564.46564.51564.53564.54
      0.00

20    0.00  0.00  0.00  0.00563.00563.00563.00563.00564.00564.00564.00564.00564.00564.06564.12564.21564.29564.35564.39564.41564.42
      0.00

21    0.00  0.00  0.00  0.00  0.00  0.00  0.00  0.00  0.00  0.00  0.00  0.00564.00564.00564.11564.17564.21564.23564.24564.25
```

274

```
         0.00

22       0.00  0.00  0.00  0.00  0.00  0.00  0.00  0.00  0.00  0.00  0.00  0.00  0.00  0.00564.00564.00564.00564.00564.00564.00
         0.00

23       0.00  0.00  0.00  0.00  0.00  0.00  0.00  0.00  0.00  0.00  0.00  0.00  0.00  0.00  0.00  0.00  0.00  0.00  0.00  0.00
         0.00
```

D.4 Input Data For Shallow System Model

```
-  SWALE MODEL  *****                                 *****  LOVE CANAL SIMULATIONS  -
WATE             EVAP RECH LSUM CHEC
        28         12                      50           HEAD      5
0
        1          5        .001      .001                  3.4E-8          8
        1          1          1
0
0
0
        1          1
12*0/0,10*563,0
0,10*563,0/0,10*563,0
0,10*563,0/0,10*563,0
0,10*563.5,0/0,10*563.5,0/0,10*564,0/0,10*564.5,0/0,10*564.5,0
0,10*565,0/0,10*565,0/0,10*565.5,0
0,10*566,0/0,10*566,0
0,10*566,0/0,10*566,0
0,10*566,0/0,10*566,0
0,10*566,0/0,10*566,0
0,10*566,0/0,10*566,0
0,10*566,0/0,10*566,0
0,10*566,0/12*0
       -1          1
12*0/0,10*1,0/12*0/12*0
12*0/12*0/12*0/12*0/12*0
12*0/12*0/12*0/12*0/12*0
12*0/12*0/12*0/12*0/12*0
12*0/12*0
12*0
12*0/12*0
12*0/12*0/12*0/12*0
   3.00E-7         1
12*0
0,10*1,0/0,10*1,0
0,10*1,0/0,10*1,0
0,10*1,0/0,10*1,0
0,10*1,0/0,10*1,0
0,10*1,0/0,10*1,0
0,10*1,0/0,10*1,0
0,10*1,0/0,10*1,0
0,10*1,0/0,10*1,0
0,10*1,0/0,10*1,0
0,10*1,0/0,10*1,0
0,10*1,0
0,10*1,0/0,10*1,0
0,10*1,0/0,10*1,0
0,10*1,0
12*0
      562.         0
       .15         0
         1         1
12*0/0,10*563,0/0,10*570,0/0,10*570.5,0/0,10*571,0/0,10*571.5,0
0,10*572,0/0,10*572.4,0/0,10*572.7,0/0,10*573,0/0,10*573.2,0
0,10*573.3,0/0,10*573.6,0/0,10*573.9,0/0,10*574.2,0
0,10*574.5,0/0,10*574.7,0/0,10*574.9,0
0,10*575,0/0,10*575,0/0,10*575,0/0,10*575,0
0,10*575,0/0,10*575,0/0,10*575,0/0,10*575,0/0,10*575,0/12*0
    1.3E-8         1
12*0
0,10*1,0/0,10*1,0
0,10*1,0/0,10*1,0
0,10*1,0/0,10*1,0
0,10*1,0/0,10*1,0
```

```
0,10*1,0/0,10*1,0
0,10*1,0/0,10*1,0
0,10*1,0/0,10*1,0
0,10*1,0/0,10*1,0
0,10*1,0/0,10*1,0
0,10*1,0/0,10*1,0
0,10*1,0/0,10*1,0
0,10*1,0/0,10*1,0
0,10*1,0/0,10*1,0
12*0
       20.         1
         1        20        15        12         9         6       4.5         3
      2.25       1.5         1         1
        10         1
         2         2         3       4.5         7      10.5      15.5        23
      34.5        52      34.5        23      15.5      10.5         7       4.5
         3         2       1.5        .9        .6        .4        .6        .9
       1.5         2         2         2
       0.5
         1         0         0     10000        50       1.4        24
  -1
```

D.5 Output From Shallow System Model

```
                                                            U. S. G. S.

                                                      FINITE-DIFFERENCE MODEL
                                                                FOR
                                                  SIMULATION OF GROUND-WATER FLOW

                                                           JANUARY, 1975

*************************************************************************************************************************************

                                                ***** LOVE CANAL SIMULATIONS  --  SWALE MODEL  *****

*************************************************************************************************************************************


SIMULATION OPTIONS:  WATE                    EVAP    RECH    LSOR    CHEC                                        HEAD

         PRINT OUT GRID BLOCK FLUX EVERY    5  TIME STEPS


                                                                  NUMBER OF ROWS =   28
                                                               NUMBER OF COLUMNS =   12
        NUMBER OF WELLS FOR WHICH DRAWDOWN IS COMPUTED AT A SPECIFIED RADIUS =    0
                                            MAXIMUM PERMITTED NUMBER OF ITERATIONS =   50

                                                          WORDS OF Y VECTOR USED =   5979

                                                       NUMBER OF PUMPING PERIODS =    1
                                                     TIME STEPS BETWEEN PRINTOUTS =    5

                                                    ERROR CRITERION FOR CLOSURE =   .1000000E-02
                                                   STEADY STATE ERROR CRITERION =   .1000000E-02

                                             SPECIFIC STORAGE OF CONFINING BED =  0.
                                                     EVAPOTRANSPIRATION RATE =   .3400000E-07
                                                       EFFECTIVE DEPTH OF ET =   8.000000

                       MULTIPLICATION FACTOR FOR TRANSMISSIVITY IN X DIRECTION =   1.000000
                                                                IN Y DIRECTION =   1.000000
```

```
                                                                                STARTING HEAD MATRIX
                                                                                --------------------
 1     0.0    0.0    0.0    0.0    0.0    0.0    0.0    0.0    0.0    0.0    0.0    0.0
 2     0.0  563.0  563.0  563.0  563.0  563.0  563.0  563.0  563.0  563.0  563.0    0.0
 3     0.0  563.0  563.0  563.0  563.0  563.0  563.0  563.0  563.0  563.0  563.0    0.0
 4     0.0  563.0  563.0  563.0  563.0  563.0  563.0  563.0  563.0  563.0  563.0    0.0
 5     0.0  563.0  563.0  563.0  563.0  563.0  563.0  563.0  563.0  563.0  563.0    0.0
 6     0.0  563.0  563.0  563.0  563.0  563.0  563.0  563.0  563.0  563.0  563.0    0.0
 7     0.0  563.5  563.5  563.5  563.5  563.5  563.5  563.5  563.5  563.5  563.5    0.0
 8     0.0  563.5  563.5  563.5  563.5  563.5  563.5  563.5  563.5  563.5  563.5    0.0
 9     0.0  564.0  564.0  564.0  564.0  564.0  564.0  564.0  564.0  564.0  564.0    0.0
10     0.0  564.5  564.5  564.5  564.5  564.5  564.5  564.5  564.5  564.5  564.5    0.0
11     0.0  564.5  564.5  564.5  564.5  564.5  564.5  564.5  564.5  564.5  564.5    0.0
12     0.0  565.0  565.0  565.0  565.0  565.0  565.0  565.0  565.0  565.0  565.0    0.0
13     0.0  565.0  565.0  565.0  565.0  565.0  565.0  565.0  565.0  565.0  565.0    0.0
14     0.0  565.5  565.5  565.5  565.5  565.5  565.5  565.5  565.5  565.5  565.5    0.0
15     0.0  566.0  566.0  566.0  566.0  566.0  566.0  566.0  566.0  566.0  566.0    0.0
16     0.0  566.0  566.0  566.0  566.0  566.0  566.0  566.0  566.0  566.0  566.0    0.0
17     0.0  566.0  566.0  566.0  566.0  566.0  566.0  566.0  566.0  566.0  566.0    0.0
18     0.0  566.0  566.0  566.0  566.0  566.0  566.0  566.0  566.0  566.0  566.0    0.0
19     0.0  566.0  566.0  566.0  566.0  566.0  566.0  566.0  566.0  566.0  566.0    0.0
20     0.0  566.0  566.0  566.0  566.0  566.0  566.0  566.0  566.0  566.0  566.0    0.0
21     0.0  566.0  566.0  566.0  566.0  566.0  566.0  566.0  566.0  566.0  566.0    0.0
22     0.0  566.0  566.0  566.0  566.0  566.0  566.0  566.0  566.0  566.0  566.0    0.0
23     0.0  566.0  566.0  566.0  566.0  566.0  566.0  566.0  566.0  566.0  566.0    0.0
24     0.0  566.0  566.0  566.0  566.0  566.0  566.0  566.0  566.0  566.0  566.0    0.0
25     0.0  566.0  566.0  566.0  566.0  566.0  566.0  566.0  566.0  566.0  566.0    0.0
26     0.0  566.0  566.0  566.0  566.0  566.0  566.0  566.0  566.0  566.0  566.0    0.0
27     0.0  566.0  566.0  566.0  566.0  566.0  566.0  566.0  566.0  566.0  566.0    0.0
28     0.0    0.0    0.0    0.0    0.0    0.0    0.0    0.0    0.0    0.0    0.0    0.0
```

```
                                          STORAGE COEFFICIENT
                                                MATRIX
                                    ------------------------------------

 1  0.00000  0.00000  0.00000  0.00000  0.00000  0.00000  0.00000  0.00000  0.00000  0.00000  0.00000  0.00000
 2  0.00000 -1.00000 -1.00000 -1.00000 -1.00000 -1.00000 -1.00000 -1.00000 -1.00000 -1.00000 -1.00000  0.00000
 3  0.00000  0.00000  0.00000  0.00000  0.00000  0.00000  0.00000  0.00000  0.00000  0.00000  0.00000  0.00000
 4  0.00000  0.00000  0.00000  0.00000  0.00000  0.00000  0.00000  0.00000  0.00000  0.00000  0.00000  0.00000
 5  0.00000  0.00000  0.00000  0.00000  0.00000  0.00000  0.00000  0.00000  0.00000  0.00000  0.00000  0.00000
 6  0.00000  0.00000  0.00000  0.00000  0.00000  0.00000  0.00000  0.00000  0.00000  0.00000  0.00000  0.00000
 7  0.00000  0.00000  0.00000  0.00000  0.00000  0.00000  0.00000  0.00000  0.00000  0.00000  0.00000  0.00000
 8  0.00000  0.00000  0.00000  0.00000  0.00000  0.00000  0.00000  0.00000  0.00000  0.00000  0.00000  0.00000
 9  0.00000  0.00000  0.00000  0.00000  0.00000  0.00000  0.00000  0.00000  0.00000  0.00000  0.00000  0.00000
10  0.00000  0.00000  0.00000  0.00000  0.00000  0.00000  0.00000  0.00000  0.00000  0.00000  0.00000  0.00000
11  0.00000  0.00000  0.00000  0.00000  0.00000  0.00000  0.00000  0.00000  0.00000  0.00000  0.00000  0.00000
12  0.00000  0.00000  0.00000  0.00000  0.00000  0.00000  0.00000  0.00000  0.00000  0.00000  0.00000  0.00000
13  0.00000  0.00000  0.00000  0.00000  0.00000  0.00000  0.00000  0.00000  0.00000  0.00000  0.00000  0.00000
14  0.00000  0.00000  0.00000  0.00000  0.00000  0.00000  0.00000  0.00000  0.00000  0.00000  0.00000  0.00000
15  0.00000  0.00000  0.00000  0.00000  0.00000  0.00000  0.00000  0.00000  0.00000  0.00000  0.00000  0.00000
16  0.00000  0.00000  0.00000  0.00000  0.00000  0.00000  0.00000  0.00000  0.00000  0.00000  0.00000  0.00000
17  0.00000  0.00000  0.00000  0.00000  0.00000  0.00000  0.00000  0.00000  0.00000  0.00000  0.00000  0.00000
18  0.00000  0.00000  0.00000  0.00000  0.00000  0.00000  0.00000  0.00000  0.00000  0.00000  0.00000  0.00000
19  0.00000  0.00000  0.00000  0.00000  0.00000  0.00000  0.00000  0.00000  0.00000  0.00000  0.00000  0.00000
20  0.00000  0.00000  0.00000  0.00000  0.00000  0.00000  0.00000  0.00000  0.00000  0.00000  0.00000  0.00000
21  0.00000  0.00000  0.00000  0.00000  0.00000  0.00000  0.00000  0.00000  0.00000  0.00000  0.00000  0.00000
22  0.00000  0.00000  0.00000  0.00000  0.00000  0.00000  0.00000  0.00000  0.00000  0.00000  0.00000  0.00000
23  0.00000  0.00000  0.00000  0.00000  0.00000  0.00000  0.00000  0.00000  0.00000  0.00000  0.00000  0.00000
24  0.00000  0.00000  0.00000  0.00000  0.00000  0.00000  0.00000  0.00000  0.00000  0.00000  0.00000  0.00000
25  0.00000  0.00000  0.00000  0.00000  0.00000  0.00000  0.00000  0.00000  0.00000  0.00000  0.00000  0.00000
26  0.00000  0.00000  0.00000  0.00000  0.00000  0.00000  0.00000  0.00000  0.00000  0.00000  0.00000  0.00000
27  0.00000  0.00000  0.00000  0.00000  0.00000  0.00000  0.00000  0.00000  0.00000  0.00000  0.00000  0.00000
28  0.00000  0.00000  0.00000  0.00000  0.00000  0.00000  0.00000  0.00000  0.00000  0.00000  0.00000  0.00000
```

```
                                   AQUIFER HYDRAULIC CONDUCTIVITY
                                               MATRIX
                                   -----------------------------------
 1  0.         0.         0.         0.         0.         0.         0.         0.         0.         0.
    0.         0.
 2  0.        .300E-06   .300E-06   .300E-06   .300E-06   .300E-06   .300E-06   .300E-06   .300E-06   .300E-06
   .300E-06   0.
 3  0.        .300E-06   .300E-06   .300E-06   .300E-06   .300E-06   .300E-06   .300E-06   .300E-06   .300E-06
   .300E-06   0.
 4  0.        .300E-06   .300E-06   .300E-06   .300E-06   .300E-06   .300E-06   .300E-06   .300E-06   .300E-06
   .300E-06   0.
 5  0.        .300E-06   .300E-06   .300E-06   .300E-06   .300E-06   .300E-06   .300E-06   .300E-06   .300E-06
   .300E-06   0.
 6  0.        .300E-06   .300E-06   .300E-06   .300E-06   .300E-06   .300E-06   .300E-06   .300E-06   .300E-06
   .300E-06   0.
 7  0.        .300E-06   .300E-06   .300E-06   .300E-06   .300E-06   .300E-06   .300E-06   .300E-06   .300E-06
   .300E-06   0.
 8  0.        .300E-06   .300E-06   .300E-06   .300E-06   .300E-06   .300E-06   .300E-06   .300E-06   .300E-06
   .300E-06   0.
 9  0.        .300E-06   .300E-06   .300E-06   .300E-06   .300E-06   .300E-06   .300E-06   .300E-06   .300E-06
   .300E-06   0.
10  0.        .300E-06   .300E-06   .300E-06   .300E-06   .300E-06   .300E-06   .300E-06   .300E-06   .300E-06
   .300E-06   0.
11  0.        .300E-06   .300E-06   .300E-06   .300E-06   .300E-06   .300E-06   .300E-06   .300E-06   .300E-06
   .300E-06   0.
12  0.        .300E-06   .300E-06   .300E-06   .300E-06   .300E-06   .300E-06   .300E-06   .300E-06   .300E-06
   .300E-06   0.
13  0.        .300E-06   .300E-06   .300E-06   .300E-06   .300E-06   .300E-06   .300E-06   .300E-06   .300E-06
   .300E-06   0.
14  0.        .300E-06   .300E-06   .300E-06   .300E-06   .300E-06   .300E-06   .300E-06   .300E-06   .300E-06
   .300E-06   0.
15  0.        .300E-06   .300E-06   .300E-06   .300E-06   .300E-06   .300E-06   .300E-06   .300E-06   .300E-06
   .300E-06   0.
16  0.        .300E-06   .300E-06   .300E-06   .300E-06   .300E-06   .300E-06   .300E-06   .300E-06   .300E-06
   .300E-06   0.
17  0.        .300E-06   .300E-06   .300E-06   .300E-06   .300E-06   .300E-06   .300E-06   .300E-06   .300E-06
   .300E-06   0.
18  0.        .300E-06   .300E-06   .300E-06   .300E-06   .300E-06   .300E-06   .300E-06   .300E-06   .300E-06
   .300E-06   0.
19  0.        .300E-06   .300E-06   .300E-06   .300E-06   .300E-06   .300E-06   .300E-06   .300E-06   .300E-06
   .300E-06   0.
20  0.        .300E-06   .300E-06   .300E-06   .300E-06   .300E-06   .300E-06   .300E-06   .300E-06   .300E-06
   .300E-06   0.
```

```
21  0.          .300E-06   .300E-06   .300E-06   .300E-06   .300E-06   .300E-06   .300E-06   .300E-06   .300E-06
   .300E-06  0.
22  0.          .300E-06   .300E-06   .300E-06   .300E-06   .300E-06   .300E-06   .300E-06   .300E-06   .300E-06
   .300E-06  0.
23  0.          .300E-06   .300E-06   .300E-06   .300E-06   .300E-06   .300E-06   .300E-06   .300E-06   .300E-06
   .300E-06  0.
24  0.          .300E-06   .300E-06   .300E-06   .300E-06   .300E-06   .300E-06   .300E-06   .300E-06   .300E-06
   .300E-06  0.
25  0.          .300E-06   .300E-06   .300E-06   .300E-06   .300E-06   .300E-06   .300E-06   .300E-06   .300E-06
   .300E-06  0.
26  0.          .300E-06   .300E-06   .300E-06   .300E-06   .300E-06   .300E-06   .300E-06   .300E-06   .300E-06
   .300E-06  0.
27  0.          .300E-06   .300E-06   .300E-06   .300E-06   .300E-06   .300E-06   .300E-06   .300E-06   .300E-06
   .300E-06  0.
28  0.          0.         0.         0.         0.         0.         0.         0.         0.         0.
    0.          0.

                                    AQUIFER BASE ELEVATION      =   562.0000

                                      SPECIFIC YIELD            =   .1500000
```

```
                                       LAND SURFACE ELEVATION
                                               MATRIX
                                  -----------------------------------

  1     0.0   0.0   0.0   0.0   0.0   0.0   0.0   0.0   0.0   0.0   0.0   0.0

  2     0.0 563.0 563.0 563.0 563.0 563.0 563.0 563.0 563.0 563.0 563.0   0.0

  3     0.0 570.0 570.0 570.0 570.0 570.0 570.0 570.0 570.0 570.0 570.0   0.0

  4     0.0 570.5 570.5 570.5 570.5 570.5 570.5 570.5 570.5 570.5 570.5   0.0

  5     0.0 571.0 571.0 571.0 571.0 571.0 571.0 571.0 571.0 571.0 571.0   0.0

  6     0.0 571.5 571.5 571.5 571.5 571.5 571.5 571.5 571.5 571.5 571.5   0.0

  7     0.0 572.0 572.0 572.0 572.0 572.0 572.0 572.0 572.0 572.0 572.0   0.0

  8     0.0 572.4 572.4 572.4 572.4 572.4 572.4 572.4 572.4 572.4 572.4   0.0

  9     0.0 572.7 572.7 572.7 572.7 572.7 572.7 572.7 572.7 572.7 572.7   0.0

 10     0.0 573.0 573.0 573.0 573.0 573.0 573.0 573.0 573.0 573.0 573.0   0.0

 11     0.0 573.2 573.2 573.2 573.2 573.2 573.2 573.2 573.2 573.2 573.2   0.0

 12     0.0 573.3 573.3 573.3 573.3 573.3 573.3 573.3 573.3 573.3 573.3   0.0

 13     0.0 573.6 573.6 573.6 573.6 573.6 573.6 573.6 573.6 573.6 573.6   0.0

 14     0.0 573.9 573.9 573.9 573.9 573.9 573.9 573.9 573.9 573.9 573.9   0.0

 15     0.0 574.2 574.2 574.2 574.2 574.2 574.2 574.2 574.2 574.2 574.2   0.0

 16     0.0 574.5 574.5 574.5 574.5 574.5 574.5 574.5 574.5 574.5 574.5   0.0

 17     0.0 574.7 574.7 574.7 574.7 574.7 574.7 574.7 574.7 574.7 574.7   0.0

 18     0.0 574.9 574.9 574.9 574.9 574.9 574.9 574.9 574.9 574.9 574.9   0.0

 19     0.0 575.0 575.0 575.0 575.0 575.0 575.0 575.0 575.0 575.0 575.0   0.0

 20     0.0 575.0 575.0 575.0 575.0 575.0 575.0 575.0 575.0 575.0 575.0   0.0

 21     0.0 575.0 575.0 575.0 575.0 575.0 575.0 575.0 575.0 575.0 575.0   0.0

 22     0.0 575.0 575.0 575.0 575.0 575.0 575.0 575.0 575.0 575.0 575.0   0.0

 23     0.0 575.0 575.0 575.0 575.0 575.0 575.0 575.0 575.0 575.0 575.0   0.0

 24     0.0 575.0 575.0 575.0 575.0 575.0 575.0 575.0 575.0 575.0 575.0   0.0

 25     0.0 575.0 575.0 575.0 575.0 575.0 575.0 575.0 575.0 575.0 575.0   0.0

 26     0.0 575.0 575.0 575.0 575.0 575.0 575.0 575.0 575.0 575.0 575.0   0.0

 27     0.0 575.0 575.0 575.0 575.0 575.0 575.0 575.0 575.0 575.0 575.0   0.0

 28     0.0   0.0   0.0   0.0   0.0   0.0   0.0   0.0   0.0   0.0   0.0   0.0
```

```
                                          AREAL RECHARGE RATE
                                                MATRIX
                                    -----------------------------------

   1  0.          0.          0.          0.          0.          0.          0.          0.          0.          0.
      0.          0.

   2  0.         .130E-07    .130E-07    .130E-07    .130E-07    .130E-07    .130E-07    .130E-07    .130E-07    .130E-07
     .130E-07    0.

   3  0.         .130E-07    .130E-07    .130E-07    .130E-07    .130E-07    .130E-07    .130E-07    .130E-07    .130E-07
     .130E-07    0.

   4  0.         .130E-07    .130E-07    .130E-07    .130E-07    .130E-07    .130E-07    .130E-07    .130E-07    .130E-07
     .130E-07    0.

   5  0.         .130E-07    .130E-07    .130E-07    .130E-07    .130E-07    .130E-07    .130E-07    .130E-07    .130E-07
     .130E-07    0.

   6  0.         .130E-07    .130E-07    .130E-07    .130E-07    .130E-07    .130E-07    .130E-07    .130E-07    .130E-07
     .130E-07    0.

   7  0.         .130E-07    .130E-07    .130E-07    .130E-07    .130E-07    .130E-07    .130E-07    .130E-07    .130E-07
     .130E-07    0.

   8  0.         .130E-07    .130E-07    .130E-07    .130E-07    .130E-07    .130E-07    .130E-07    .130E-07    .130E-07
     .130E-07    0.

   9  0.         .130E-07    .130E-07    .130E-07    .130E-07    .130E-07    .130E-07    .130E-07    .130E-07    .130E-07
     .130E-07    0.

  10  0.         .130E-07    .130E-07    .130E-07    .130E-07    .130E-07    .130E-07    .130E-07    .130E-07    .130E-07
     .130E-07    0.

  11  0.         .130E-07    .130E-07    .130E-07    .130E-07    .130E-07    .130E-07    .130E-07    .130E-07    .130E-07
     .130E-07    0.

  12  0.         .130E-07    .130E-07    .130E-07    .130E-07    .130E-07    .130E-07    .130E-07    .130E-07    .130E-07
     .130E-07    0.

  13  0.         .130E-07    .130E-07    .130E-07    .130E-07    .130E-07    .130E-07    .130E-07    .130E-07    .130E-07
     .130E-07    0.

  14  0.         .130E-07    .130E-07    .130E-07    .130E-07    .130E-07    .130E-07    .130E-07    .130E-07    .130E-07
     .130E-07    0.

  15  0.         .130E-07    .130E-07    .130E-07    .130E-07    .130E-07    .130E-07    .130E-07    .130E-07    .130E-07
     .130E-07    0.

  16  0.         .130E-07    .130E-07    .130E-07    .130E-07    .130E-07    .130E-07    .130E-07    .130E-07    .130E-07
     .130E-07    0.

  17  0.         .130E-07    .130E-07    .130E-07    .130E-07    .130E-07    .130E-07    .130E-07    .130E-07    .130E-07
     .130E-07    0.

  18  0.         .130E-07    .130E-07    .130E-07    .130E-07    .130E-07    .130E-07    .130E-07    .130E-07    .130E-07
     .130E-07    0.

  19  0.         .130E-07    .130E-07    .130E-07    .130E-07    .130E-07    .130E-07    .130E-07    .130E-07    .130E-07
     .130E-07    0.

  20  0.         .130E-07    .130E-07    .130E-07    .130E-07    .130E-07    .130E-07    .130E-07    .130E-07    .130E-07
     .130E-07    0.
```

```
21  0.          .130E-07   .130E-07   .130E-07   .130E-07   .130E-07   .130E-07   .130E-07   .130E-07   .130E-07
     .130E-07  0.
22  0.          .130E-07   .130E-07   .130E-07   .130E-07   .130E-07   .130E-07   .130E-07   .130E-07   .130E-07
     .130E-07  0.
23  0.          .130E-07   .130E-07   .130E-07   .130E-07   .130E-07   .130E-07   .130E-07   .130E-07   .130E-07
     .130E-07  0.
24  0.          .130E-07   .130E-07   .130E-07   .130E-07   .130E-07   .130E-07   .130E-07   .130E-07   .130E-07
     .130E-07  0.
25  0.          .130E-07   .130E-07   .130E-07   .130E-07   .130E-07   .130E-07   .130E-07   .130E-07   .130E-07
     .130E-07  0.
26  0.          .130E-07   .130E-07   .130E-07   .130E-07   .130E-07   .130E-07   .130E-07   .130E-07   .130E-07
     .130E-07  0.
27  0.          .130E-07   .130E-07   .130E-07   .130E-07   .130E-07   .130E-07   .130E-07   .130E-07   .130E-07
     .130E-07  0.
28  0.          0.         0.         0.         0.         0.         0.         0.         0.         0.
    0.          0.
```

```
                          GRID SPACING IN PROTOTYPE IN X DIRECTION
                          ----------------------------------------

   20.      400.      300.      240.      180.      120.       90.       60.       45.       30.       20.       20.

                          GRID SPACING IN PROTOTYPE IN Y DIRECTION
                          ----------------------------------------

   20.       20.       30.       45.       70.      105.      155.      230.      345.      520.      345.      230.
  155.      105.       70.       45.       30.       20.       15.        9.        6.        4.        6.        9.
   15.       20.       20.       20.

                    SOLUTION BY LDU FACTORIZATION ASSUMING D4 ORDERING
                    ##################################################

                                    BETA = 1.00

                          ITERATIONS:  MINIMUM =    0
                                       MAXIMUM =   50
                                         THETA =  .50

              |||||WARNING|||||MINIMUM DIMENSIONS FOR ARRAYS USED BY THIS METHOD ARE AS FOLLOWS:

                                      AU:  125 BY    5
                                      AL:  125 BY   13
                                      IC:  125 BY    5
                                       B:  250
                                      IN:   26 BY   10

                              PUMPING PERIOD NO.   1:  10000.00 DAYS
                              ----------------------------------------

                                NUMBER OF TIME STEPS=     24

                                     DELT IN HOURS =     21.341

                                MULTIPLIER FOR DELT =      1.400

                                          0 WELLS
                                          -------

                          I          J    PUMPING RATE  WELL RADIUS


        ROW    2
                  CONSTANT HEAD FLUX RATES ... LLL/T
-.335E-06 -.251E-06 -.201E-06 -.151E-06 -.101E-06 -.754E-07 -.503E-07 -.377E-07 -.251E-07 -.168E-07
                  ET RATES ... LLL/T
 0.         0.         0.         0.         0.         0.         0.         0.         0.         0.

        ROW    3
                  CONSTANT HEAD FLUX RATES ... LLL/T
 0.         0.         0.         0.         0.         0.         0.         0.         0.         0.
                  ET RATES ... LLL/T
```

```
      ROW    4
                    CONSTANT HEAD FLUX RATES ... LLL/T
 0.        0.         0.         0.         0.         0.         0.         0.         0.         0.
                    ET RATES ... LLL/T
 .446E-04  .335E-04  .268E-04  .201E-04  .134E-04  .100E-04  .670E-05  .502E-05  .335E-05  .223E-05

      ROW    5
                    CONSTANT HEAD FLUX RATES ... LLL/T
 0.        0.         0.         0.         0.         0.         0.         0.         0.         0.
                    ET RATES ... LLL/T
 .119E-04  .892E-05  .714E-05  .535E-05  .357E-05  .268E-05  .178E-05  .134E-05  .892E-06  .595E-06

      ROW    6
                    CONSTANT HEAD FLUX RATES ... LLL/T
 0.        0.         0.         0.         0.         0.         0.         0.         0.         0.
                    ET RATES ... LLL/T
 0.        0.         0.         0.         0.         0.         0.         0.         0.         0.

      ROW    7
                    CONSTANT HEAD FLUX RATES ... LLL/T
 0.        0.         0.         0.         0.         0.         0.         0.         0.         0.
                    ET RATES ... LLL/T
 0.        0.         0.         0.         0.         0.         0.         0.         0.         0.

      ROW    8
                    CONSTANT HEAD FLUX RATES ... LLL/T
 0.        0.         0.         0.         0.         0.         0.         0.         0.         0.
                    ET RATES ... LLL/T
 0.        0.         0.         0.         0.         0.         0.         0.         0.         0.

      ROW    9
                    CONSTANT HEAD FLUX RATES ... LLL/T
 0.        0.         0.         0.         0.         0.         0.         0.         0.         0.
                    ET RATES ... LLL/T
 0.        0.         0.         0.         0.         0.         0.         0.         0.         0.

      ROW   10
                    CONSTANT HEAD FLUX RATES ... LLL/T
 0.        0.         0.         0.         0.         0.         0.         0.         0.         0.
                    ET RATES ... LLL/T
 0.        0.         0.         0.         0.         0.         0.         0.         0.         0.

      ROW   11
                    CONSTANT HEAD FLUX RATES ... LLL/T
 0.        0.         0.         0.         0.         0.         0.         0.         0.         0.
                    ET RATES ... LLL/T
 0.        0.         0.         0.         0.         0.         0.         0.         0.         0.

      ROW   12
                    CONSTANT HEAD FLUX RATES ... LLL/T
 0.        0.         0.         0.         0.         0.         0.         0.         0.         0.
                    ET RATES ... LLL/T
 0.        0.         0.         0.         0.         0.         0.         0.         0.         0.

      ROW   13
                    CONSTANT HEAD FLUX RATES ... LLL/T
 0.        0.         0.         0.         0.         0.         0.         0.         0.         0.
                    ET RATES ... LLL/T
 0.        0.         0.         0.         0.         0.         0.         0.         0.         0.

      ROW   14
                    CONSTANT HEAD FLUX RATES ... LLL/T
 0.        0.         0.         0.         0.         0.         0.         0.         0.         0.
                    ET RATES ... LLL/T
 0         0          0          0          0          0          0          0          0          0
```

```
           ROW   15
                     CONSTANT HEAD FLUX RATES ... LLL/T
  0.        0.          0.         0.         0.         0.         0.         0.         0.         0.
                     ET RATES ... LLL/T
  0.        0.          0.         0.         0.         0.         0.         0.         0.         0.

           ROW   16
                     CONSTANT HEAD FLUX RATES ... LLL/T
  0.        0.          0.         0.         0.         0.         0.         0.         0.         0.
                     ET RATES ... LLL/T
  0.        0.          0.         0.         0.         0.         0.         0.         0.         0.

           ROW   17
                     CONSTANT HEAD FLUX RATES ... LLL/T
  0.        0.          0.         0.         0.         0.         0.         0.         0.         0.
                     ET RATES ... LLL/T
  0.        0.          0.         0.         0.         0.         0.         0.         0.         0.

           ROW   18
                     CONSTANT HEAD FLUX RATES ... LLL/T
  0.        0.          0.         0.         0.         0.         0.         0.         0.         0.
                     ET RATES ... LLL/T
  0.        0.          0.         0.         0.         0.         0.         0.         0.         0.

           ROW   19
                     CONSTANT HEAD FLUX RATES ... LLL/T
  0.        0.          0.         0.         0.         0.         0.         0.         0.         0.
                     ET RATES ... LLL/T
  0.        0.          0.         0.         0.         0.         0.         0.         0.         0.

           ROW   20
                     CONSTANT HEAD FLUX RATES ... LLL/T
  0.        0.          0.         0.         0.         0.         0.         0.         0.         0.
                     ET RATES ... LLL/T
  0.        0.          0.         0.         0.         0.         0.         0.         0.         0.

           ROW   21
                     CONSTANT HEAD FLUX RATES ... LLL/T
  0.        0.          0.         0.         0.         0.         0.         0.         0.         0.
                     ET RATES ... LLL/T
  0.        0.          0.         0.         0.         0.         0.         0.         0.         0.

           ROW   22
                     CONSTANT HEAD FLUX RATES ... LLL/T
  0.        0.          0.         0.         0.         0.         0.         0.         0.         0.
                     ET RATES ... LLL/T
  0.        0.          0.         0.         0.         0.         0.         0.         0.         0.

           ROW   23
                     CONSTANT HEAD FLUX RATES ... LLL/T
  0.        0.          0.         0.         0.         0.         0.         0.         0.         0.
                     ET RATES ... LLL/T
  0.        0.          0.         0.         0.         0.         0.         0.         0.         0.

           ROW   24
                     CONSTANT HEAD FLUX RATES ... LLL/T
  0.        0.          0.         0.         0.         0.         0.         0.         0.         0.
                     ET RATES ... LLL/T
  0.        0.          0.         0.         0.         0.         0.         0.         0.         0.

           ROW   25
                     CONSTANT HEAD FLUX RATES ... LLL/T
  0.        0.          0.         0.         0.         0.         0.         0.         0.         0.
                     ET RATES ... LLL/T
  0.        0.          0.         0.         0.         0.         0.         0.         0.         0.
```

```
        ROW   26
                     CONSTANT HEAD FLUX RATES ... LLL/T
   0.        0.        0.        0.        0.        0.        0.        0.        0.        0.
                     ET RATES ... LLL/T
   0.        0.        0.        0.        0.        0.        0.        0.        0.        0.
        ROW   27
                     CONSTANT HEAD FLUX RATES ... LLL/T
   0.        0.        0.        0.        0.        0.        0.        0.        0.        0.
                     ET RATES ... LLL/T
   0.        0.        0.        0.        0.        0.        0.        0.        0.        0.
```

```
                    ----------------------------------------------------------
                    &           TIME STEP NUMBER =         5                 &
                    ----------------------------------------------------------

                         SIZE OF TIME STEP IN SECONDS=      413188.44

                              TOTAL SIMULATION TIME IN SECONDS=    1177268.68
                                                       MINUTES=      19621.14
                                                         HOURS=        327.02
                                                          DAYS=         13.63
                                                         YEARS=           .04

                    DURATION OF CURRENT PUMPING PERIOD IN DAYS=         13.63
                                                         YEARS=           .04


     CUMULATIVE MASS BALANCE:                 L**3                RATES FOR THIS TIME STEP:                L**3/T
     ------------------------                                     -------------------------
                                                                                     STORAGE =           -.0499
           SOURCES:                                                                 RECHARGE =            .0503
           --------                                                            CONSTANT FLUX =           0.0000
                   STORAGE =             -58731.36                                   PUMPING =           0.0000
                  RECHARGE =              59181.56                        EVAPOTRANSPIRATION =           -.0004
             CONSTANT FLUX =                  0.00                             CONSTANT HEAD:
             CONSTANT HEAD =                  0.00                                        IN =           0.0000
                   LEAKAGE =                  0.00                                       OUT =           -.0000
             TOTAL SOURCES =                450.20                                  LEAKAGE:
                                                                FROM PREVIOUS PUMPING PERIOD =           0.0000
           DISCHARGES:                                                                 TOTAL =           0.0000
           -----------
        EVAPOTRANSPIRATION =                449.29                              SUM OF RATES =           -.0000
             CONSTANT HEAD =                   .91
           QUANTITY PUMPED =                  0.00
                   LEAKAGE =                  0.00
           TOTAL DISCHARGE =                450.20

        DISCHARGE-SOURCES =                    .00
      PER CENT DIFFERENCE =                    .00


 MAXIMUM HEAD CHANGE FOR EACH ITERATION:
 ---------------------------------------

       .0179      .0000

 MAXIMUM CHANGE IN HEAD FOR THIS TIME STEP =       .036
 -------------------------------------------------------

 TIME STEP :  1  2  3  4  5
 ----------

 ITERATIONS:  1  1  1  1  1
 ----------
```

```
                                  HEAD MATRIX
                                  -----------
           1   0.00  0.00  0.00  0.00  0.00  0.00  0.00  0.00  0.00  0.00  0.00  0.00
           2   0.00563.00563.00563.00563.00563.00563.00563.00563.00563.00563.00  0.00
           3   0.00563,07563.07563.07563.07563.07563.07563.07563.07563.07563.07  0.00
           4   0.00563.08563.08563.08563.08563.08563.08563.08563.08563.08563.08  0.00
           5   0.00563.10563.10563.10563.10563,10563.10563.10563.10563.10563.10  0.00
           6   0.00563.10563.10563.10563.10563.10563.10563.10563.10563,10563.10  0.00
           7   0.00563.60563.60563.60563.60563.60563.60563,60563.60563.60563.60  0.00
           8   0.00563.60563.60563.60563.60563.60563.60563.60563.60563.60563.60  0.00
           9   0.00564.10564.10564.10564.10564.10564.10564.10564.10564.10564.10  0.00
          10   0.00564.60564.60564.60564.60564.60564.60564,60564,60564.60564.60  0.00
          11   0.00564.60564.60564.60564.60564.60564.60564.60564.60564.60564,60  0.00
          12   0.00565.10565.10565.10565.10565.10565.10565.10565.10565.10565.10  0.00
          13   0.00565.10565.10565.10565.10565.10565.10565.10565.10565.10565.10  0.00
          14   0.00565.60565.60565.60565.60565.60565.60565.60565.60565.60565.60  0.00
          15   0.00566.10566.10566.10566.10566.10566.10566.10566.10566.10566.10  0.00
          16   0.00566.10566.10566.10566.10566.10566.10566.10566.10566.10566.10  0.00
          17   0.00566.10566.10566.10566.10566.10566.10566.10566.10566.10566.10  0.00
          18   0.00566.10566.10566.10566.10566.10566.10566.10566.10566.10566.10  0.00
          19   0.00566.10566.10566.10566.10566.10566.10566.10566.10566.10566.10  0.00
          20   0.00566.10566.10566.10566.10566.10566.10566.10566.10566.10566.10  0.00
          21   0.00566.10566.10566.10566.10566.10566.10566.10566.10566.10566.10  0.00
          22   0.00566.10566.10566.10566.10566.10566.10566.10566.10566.10566.10  0.00
          23   0.00566.10566.10566.10566.10566.10566.10566.10566.10566.10566.10  0.00
          24   0.00566.10566.10566.10566.10566.10566.10566.10566.10566.10566.10  0.00
          25   0.00566.10566.10566.10566.10566.10566.10566.10566.10566.10566.10  0.00
          26   0.00566.10566.10566.10566.10566.10566,10566.10566.10566.10566.10  0.00
          27   0.00566,10566.10566.10566.10566.10566.10566.10566,10566.10566.10  0.00
          28   0.00  0.00  0.00  0.00  0.00  0.00  0.00  0.00  0.00  0.00  0.00  0.00
   ROW    2
              CONSTANT HEAD FLUX RATES ... LLL/T
-.221E-05 -.166E-05 -.133E-05 -.995E-06 -.664E-06 -.498E-06 -.332E-06 -.249E-06 -.166E-06 -.111E-06
              ET RATES ... LLL/T
0.        0.        0.        0.        0.        0.        0.        0.        0.        0.
```

```
       ROW    3
                 CONSTANT HEAD FLUX RATES ... LLL/T
 0.        0.        0.        0.        0.        0.        0.        0.        0.        0.
                 ET RATES ... LLL/T
  .706E-04  .529E-04  .424E-04  .318E-04  .212E-04  .159E-04  .106E-04  .794E-05  .529E-05  .353E-05

       ROW    4
                 CONSTANT HEAD FLUX RATES ... LLL/T
 0.        0.        0.        0.        0.        0.        0.        0.        0.        0.
                 ET RATES ... LLL/T
  .751E-04  .563E-04  .451E-04  .338E-04  .225E-04  .169E-04  .113E-04  .845E-05  .563E-05  .376E-05

       ROW    5
                 CONSTANT HEAD FLUX RATES ... LLL/T
 0.        0.        0.        0.        0.        0.        0.        0.        0.        0.
                 ET RATES ... LLL/T
  .686E-04  .514E-04  .412E-04  .309E-04  .206E-04  .154E-04  .103E-04  .772E-05  .514E-05  .343E-05

       ROW    6
                 CONSTANT HEAD FLUX RATES ... LLL/T
 0.        0.        0.        0.        0.        0.        0.        0.        0.        0.
                 ET RATES ... LLL/T
  .255E-04  .191E-04  .153E-04  .115E-04  .764E-05  .573E-05  .382E-05  .286E-05  .191E-05  .127E-05

       ROW    7
                 CONSTANT HEAD FLUX RATES ... LLL/T
 0.        0.        0.        0.        0.        0.        0.        0.        0.        0.
                 ET RATES ... LLL/T
  .372E-04  .279E-04  .223E-04  .168E-04  .112E-04  .838E-05  .558E-05  .419E-05  .279E-05  .186E-05

       ROW    8
                 CONSTANT HEAD FLUX RATES ... LLL/T
 0.        0.        0.        0.        0.        0.        0.        0.        0.        0.
                 ET RATES ... LLL/T
 0.        0.        0.        0.        0.        0.        0.        0.        0.        0.

       ROW    9
                 CONSTANT HEAD FLUX RATES ... LLL/T
 0.        0.        0.        0.        0.        0.        0.        0.        0.        0.
                 ET RATES ... LLL/T
 0.        0.        0.        0.        0.        0.        0.        0.        0.        0.

       ROW   10
                 CONSTANT HEAD FLUX RATES ... LLL/T
 0.        0.        0.        0.        0.        0.        0.        0.        0.        0.
                 ET RATES ... LLL/T
  .125E-03  .940E-04  .752E-04  .564E-04  .376E-04  .282E-04  .188E-04  .141E-04  .940E-05  .627E-05

       ROW   11
                 CONSTANT HEAD FLUX RATES ... LLL/T
 0.        0.        0.        0.        0.        0.        0.        0.        0.        0.
                 ET RATES ... LLL/T
 0.        0.        0.        0.        0.        0.        0.        0.        0.        0.

       ROW   12
                 CONSTANT HEAD FLUX RATES ... LLL/T
 0.        0.        0.        0.        0.        0.        0.        0.        0.        0.
                 ET RATES ... LLL/T
  .126E-03  .946E-04  .757E-04  .568E-04  .379E-04  .284E-04  .189E-04  .142E-04  .946E-05  .631E-05

       ROW   13
                 CONSTANT HEAD FLUX RATES ... LLL/T
 0.        0.        0.        0.        0.        0.        0.        0.        0.        0.
                 ET RATES ... LLL/T
       ROW   14
                   CONSTANT HEAD FLUX RATES ... LLL/T
 0.        0.        0.        0.        0.        0.        0.        0.        0.        0.
                   ET RATES ... LLL/T
 .419E-04  .314E-04  .251E-04  .189E-04  .126E-04  .943E-05  .628E-05  .471E-05  .314E-05  .209E-05

       ROW   15
                   CONSTANT HEAD FLUX RATES ... LLL/T
 0.        0.        0.        0.        0.        0.        0.        0.        0.        0.
                   ET RATES ... LLL/T
 .483E-04  .362E-04  .290E-04  .217E-04  .145E-04  .109E-04  .724E-05  .543E-05  .362E-05  .241E-05

       ROW   16
                   CONSTANT HEAD FLUX RATES ... LLL/T
 0.        0.        0.        0.        0.        0.        0.        0.        0.        0.
                   ET RATES ... LLL/T
 .108E-04  .812E-05  .650E-05  .487E-05  .325E-05  .244E-05  .162E-05  .122E-05  .812E-06  .541E-06

       ROW   17
                   CONSTANT HEAD FLUX RATES ... LLL/T
 0.        0.        0.        0.        0.        0.        0.        0.        0.        0.
                   ET RATES ... LLL/T
 0.        0.        0.        0.        0.        0.        0.        0.        0.        0.

       ROW   18
                   CONSTANT HEAD FLUX RATES ... LLL/T
 0.        0.        0.        0.        0.        0.        0.        0.        0.        0.
                   ET RATES ... LLL/T
 0.        0.        0.        0.        0.        0.        0.        0.        0.        0.

       ROW   19
                   CONSTANT HEAD FLUX RATES ... LLL/T
 0.        0.        0.        0.        0.        0.        0.        0.        0.        0.
                   ET RATES ... LLL/T
 0.        0.        0.        0.        0.        0.        0.        0.        0.        0.

       ROW   20
                   CONSTANT HEAD FLUX RATES ... LLL/T
 0.        0.        0.        0.        0.        0.        0.        0.        0.        0.
                   ET RATES ... LLL/T
 0.        0.        0.        0.        0.        0.        0.        0.        0.        0.

       ROW   21
                   CONSTANT HEAD FLUX RATES ... LLL/T
 0.        0.        0.        0.        0.        0.        0.        0.        0.        0.
                   ET RATES ... LLL/T
 0.        0.        0.        0.        0.        0.        0.        0.        0.        0.

       ROW   22
                   CONSTANT HEAD FLUX RATES ... LLL/T
 0.        0.        0.        0.        0.        0.        0.        0.        0.        0.
                   ET RATES ... LLL/T
 0.        0.        0.        0.        0.        0.        0.        0.        0.        0.

       ROW   23
                   CONSTANT HEAD FLUX RATES ... LLL/T
 0.        0.        0.        0.        0.        0.        0.        0.        0.        0.
                   ET RATES ... LLL/T
 0.        0.        0.        0.        0.        0.        0.        0.        0.        0.

       ROW   24
                   CONSTANT HEAD FLUX RATES ... LLL/T
 0.        0.        0.        0.        0.        0.        0.        0.        0.        0.
                   ET RATES ... LLL/T
```

```
         ROW   25
                     CONSTANT HEAD FLUX RATES ... LLL/T
   0.        0.        0.        0.        0.        0.        0.        0.        0.        0.
                     ET RATES ... LLL/T
   0.        0.        0.        0.        0.        0.        0.        0.        0.        0.
         ROW   26
                     CONSTANT HEAD FLUX RATES ... LLL/T
   0.        0.        0.        0.        0.        0.        0.        0.        0.        0.
                     ET RATES ... LLL/T
   0.        0.        0.        0.        0.        0.        0.        0.        0.        0.
         ROW   27
                     CONSTANT HEAD FLUX RATES ... LLL/T
   0.        0.        0.        0.        0.        0.        0.        0.        0.        0.
                     ET RATES ... LLL/T
   0.        0.        0.        0.        0.        0.        0.        0.        0.        0.
```

```
                                                   --------------------------------------------------------
                                                   *              TIME STEP NUMBER =         10            *
                                                   --------------------------------------------------------

                                                        SIZE OF TIME STEP IN SECONDS=    2222226.58

                                                            TOTAL SIMULATION TIME IN SECONDS=     7508902.17
                                                                                    MINUTES=      125148.37
                                                                                      HOURS=        2085.81
                                                                                       DAYS=          86.91
                                                                                      YEARS=            .24

                                                  DURATION OF CURRENT PUMPING PERIOD IN DAYS=          86.91
                                                                                      YEARS=            .24

                  CUMULATIVE MASS BALANCE:                  L**3
                  ------------------------                                    RATES FOR THIS TIME STEP:              L**3/T
                                                                              -------------------------
                       SOURCES:
                       --------                                                              STORAGE =            -.0479
                                 STORAGE =            -368634.74                            RECHARGE =             .0503
                                RECHARGE =             377474.16                       CONSTANT FLUX =            0.0000
                           CONSTANT FLUX =                  0.00                             PUMPING =            0.0000
                           CONSTANT HEAD =                  0.00                  EVAPOTRANSPIRATION =            -.0024
                                 LEAKAGE =                  0.00                      CONSTANT HEAD:
                           TOTAL SOURCES =               8839.42                                  IN =            0.0000
                                                                                                 OUT =            -.0000
                       DISCHARGES:                                                          LEAKAGE:
                       -----------                                        FROM PREVIOUS PUMPING PERIOD =          0.0000
                      EVAPOTRANSPIRATION =               8803.28                               TOTAL =            0.0000
                           CONSTANT HEAD =                 36.15
                         QUANTITY PUMPED =                  0.00                        SUM OF RATES =            -.0000
                                 LEAKAGE =                  0.00
                         TOTAL DISCHARGE =               8839.42

                      DISCHARGE-SOURCES =                    .00
                   PER CENT DIFFERENCE =                    .00

          MAXIMUM HEAD CHANGE FOR EACH ITERATION:
          ---------------------------------------

                .0965        .0031        .0000

          MAXIMUM CHANGE IN HEAD FOR THIS TIME STEP =       .193
          -----------------------------------------------------

          TIME STEP :  1  2  3  4  5  6  7  8  9 10
          ----------

          ITERATIONS:  1  1  1  1  1  1  1  1  2  2
          ----------
```

```
                              HEAD MATRIX
                              -----------

      1    0.00  0.00  0.00  0.00  0.00  0.00  0.00  0.00  0.00  0.00  0.00  0.00
      2    0.00563.00563.00563.00563.00563.00563.00563.00563.00563.00563.00  0.00
      3    0.00563.38563.38563.38563.38563.38563.38563.38563.38563.38563.38  0.00
      4    0.00563.48563.48563.48563.48563.48563.48563.48563.48563.48563.48  0.00
      5    0.00563.58563.58563.58563.58563.58563.58563.58563.58563.58563.58  0.00
      6    0.00563.64563.64563.64563.64563.64563.64563.64563.64563.64563.64  0.00
      7    0.00564.14564.14564.14564.14564.14564.14564.14564.14564.14564.14  0.00
      8    0.00564.15564.15564.15564.15564.15564.15564.15564.15564.15564.15  0.00
      9    0.00564.65564.65564.65564.65564.65564.65564.65564.65564.65564.65  0.00
     10    0.00565.14565.14565.14565.14565.14565.14565.14565.14565.14565.14  0.00
     11    0.00565.15565.15565.15565.15565.15565.15565.15565.15565.15565.15  0.00
     12    0.00565.62565.62565.62565.62565.62565.62565.62565.62565.62565.62  0.00
     13    0.00565.65565.65565.65565.65565.65565.65565.65565.65565.65565.65  0.00
     14    0.00566.13566.13566.13566.13566.13566.13566.13566.13566.13566.13  0.00
     15    0.00566.61566.61566.61566.61566.61566.61566.61566.61566.61566.61  0.00
     16    0.00566.64566.64566.64566.64566.64566.64566.64566.64566.64566.64  0.00
     17    0.00566.65566.65566.65566.65566.65566.65566.65566.65566.65566.65  0.00
     18    0.00566.65566.65566.65566.65566.65566.65566.65566.65566.65566.65  0.00
     19    0.00566.65566.65566.65566.65566.65566.65566.65566.65566.65566.65  0.00
     20    0.00566.65566.65566.65566.65566.65566.65566.65566.65566.65566.65  0.00
     21    0.00566.65566.65566.65566.65566.65566.65566.65566.65566.65566.65  0.00
     22    0.00566.65566.65566.65566.65566.65566.65566.65566.65566.65566.65  0.00
     23    0.00566.65566.65566.65566.65566.65566.65566.65566.65566.65566.65  0.00
     24    0.00566.65566.65566.65566.65566.65566.65566.65566.65566.65566.65  0.00
     25    0.00566.65566.65566.65566.65566.65566.65566.65566.65566.65566.65  0.00
     26    0.00566.65566.65566.65566.65566.65566.65566.65566.65566.65566.65  0.00
     27    0.00566.65566.65566.65566.65566.65566.65566.65566.65566.65566.65  0.00
     28    0.00  0.00  0.00  0.00  0.00  0.00  0.00  0.00  0.00  0.00  0.00  0.00

    ROW     2
              CONSTANT HEAD FLUX RATES ... LLL/T
-.941E-05 -.706E-05 -.565E-05 -.424E-05 -.282E-05 -.212E-05 -.141E-05 -.106E-05 -.706E-06 -.471E-06
              ET RATES ... LLL/T
```

```
       ROW    3
                    CONSTANT HEAD FLUX RATES ... LLL/T
 0.         0.          0.         0.         0.         0.         0.         0.         0.         0.
                   ET RATES ... LLL/T
 .117E-03  .879E-04  .703E-04  .527E-04  .351E-04  .264E-04  .176E-04  .132E-04  .879E-05  .586E-05

       ROW    4
                    CONSTANT HEAD FLUX RATES ... LLL/T
 0.         0.          0.         0.         0.         0.         0.         0.         0.         0.
                   ET RATES ... LLL/T
 .167E-03  .125E-03  .100E-03  .751E-04  .501E-04 ,.375E-04  .250E-04  .188E-04  .125E-04  .834E-05

       ROW    5
                    CONSTANT HEAD FLUX RATES ... LLL/T
 0.         0.          0.         0.         0.         0.         0.         0.         0.         0.
                   ET RATES ... LLL/T
 .240E-03  .180E-03  .144E-03  .108E-03  .719E-04  .540E-04  .360E-04  .270E-04  .180E-04  .120E-04

       ROW    6
                    CONSTANT HEAD FLUX RATES ... LLL/T
 0.         0.          0.         0.         0.         0.         0.         0.         0.         0.
                   ET RATES ... LLL/T
 .328E-03  .246E-03  .197E-03  .148E-03  .984E-04  .738E-04  .492E-04  .369E-04  .246E-04  .164E-04

       ROW    7
                    CONSTANT HEAD FLUX RATES ... LLL/T
 0.         0.          0.         0.         0.         0.         0.         0.         0.         0.
                   ET RATES ... LLL/T
 .483E-03  .362E-03  .290E-03  .217E-03  .145E-03  .109E-03  .724E-04  .543E-04  .362E-04  .241E-04

       ROW    8
                    CONSTANT HEAD FLUX RATES ... LLL/T
 0.         0.          0.         0.         0.         0.         0.         0.         0.         0.
                   ET RATES ... LLL/T
 .653E-03  .490E-03  .392E-03  .294E-03  .196E-03  .147E-03  .980E-04  .735E-04  .490E-04  .327E-04

       ROW    9
                    CONSTANT HEAD FLUX RATES ... LLL/T
 0.         0.          0.         0.         0.         0.         0.         0.         0.         0.
                   ET RATES ... LLL/T
 .103E-02  .772E-03  .617E-03  .463E-03  .309E-03  .232E-03  .154E-03  .116E-03  .772E-04  .515E-04

       ROW   10
                    CONSTANT HEAD FLUX RATES ... LLL/T
 0.         0.          0.         0.         0.         0.         0.         0.         0.         0.
                   ET RATES ... LLL/T
 .162E-02  .122E-02  .973E-03 .730E-03  .487E-03  .365E-03  .243E-03  .182E-03  .122E-03  .811E-04

       ROW   11
                    CONSTANT HEAD FLUX RATES ... LLL/T
 0.         0.          0.         0.         0.         0.         0.         0.         0.         0.
                   ET RATES ... LLL/T
 .103E-02  .772E-03  .618E-03  .463E-03  .309E-03  .232E-03  .154E-03  .116E-03  .772E-04  .515E-04

       ROW   12
                    CONSTANT HEAD FLUX RATES ... LLL/T
 0.         0.          0.         0.         0.  .      0.         0.         0.         0.         0.
                   ET RATES ... LLL/T
 .747E-03  .560E-03  .448E-03  .336E-03  .224E-03  .168E-03  .112E-03  .840E-04  .560E-04  .374E-04

       ROW   13
                    CONSTANT HEAD FLUX RATES ... LLL/T
 0.         0.          0.         0.         0.         0.         0.         0.         0.         0.
                   ET RATES ... LLL/T
 [illegible] [illegible] [illegible] [illegible] [illegible] [illegible] .711E-04 [illegible] .356E-04 .237E-04
```

```
        ROW   14
                    CONSTANT HEAD FLUX RATES ... LLL/T
 0.        0.        0.        0.        0.        0.        0.        0.        0.        0.
                    ET RATES ... LLL/T
 .335E-03  .251E-03  .201E-03  .151E-03  .101E-03  .754E-04  .503E-04  .377E-04  .251E-04  .168E-04
        ROW   15
                    CONSTANT HEAD FLUX RATES ... LLL/T
 0.        0.        0.        0.        0.        0.        0.        0.        0.        0.
                    ET RATES ... LLL/T
 .231E-03  .173E-03  .139E-03  .104E-03  .693E-04  .520E-04  .346E-04  .260E-04  .173E-04  .115E-04
        ROW   16
                    CONSTANT HEAD FLUX RATES ... LLL/T
 0.        0.        0.        0.        0.        0.        0.        0.        0.        0.
                    ET RATES ... LLL/T
 .140E-03  .105E-03  .842E-04  .631E-04  .421E-04  .316E-04  .210E-04  .158E-04  .105E-04  .702E-05
        ROW   17
                    CONSTANT HEAD FLUX RATES ... LLL/T
 0.        0.        0.        0.        0.        0.        0.        0.        0.        0.
                    ET RATES ... LLL/T
 .897E-04  .673E-04  .538E-04  .404E-04  .269E-04  .202E-04  .135E-04  .101E-04  .673E-05  .449E-05
        ROW   18
                    CONSTANT HEAD FLUX RATES ... LLL/T
 0.        0.        0.        0.        0.        0.        0.        0.        0.        0.
                    ET RATES ... LLL/T
 .564E-04  .423E-04  .338E-04  .254E-04  .169E-04  .127E-04  .845E-05  .634E-05  .423E-05  .282E-05
        ROW   19
                    CONSTANT HEAD FLUX RATES ... LLL/T
 0.        0.        0.        0.        0.        0.        0.        0.        0.        0.
                    ET RATES ... LLL/T
 .409E-04  .307E-04  .245E-04  .184E-04  .123E-04  .920E-05  .614E-05  .460E-05  .307E-05  .205E-05
        ROW   20
                    CONSTANT HEAD FLUX RATES ... LLL/T
 0.        0.        0.        0.        0.        0.        0.        0.        0.        0.
                    ET RATES ... LLL/T
 .247E-04  .185E-04  .148E-04  .111E-04  .742E-05  .556E-05  .371E-05  .278E-05  .185E-05  .124E-05
        ROW   21
                    CONSTANT HEAD FLUX RATES ... LLL/T
 0.        0.        0.        0.        0.        0.        0.        0.        0.        0.
                    ET RATES ... LLL/T
 .165E-04  .124E-04  .992E-05  .744E-05  .496E-05  .372E-05  .248E-05  .186E-05  .124E-05  .826E-06
        ROW   22
                    CONSTANT HEAD FLUX RATES ... LLL/T
 0.        0.        0.        0.        0.        0.        0.        0.        0.        0.
                    ET RATES ... LLL/T
 .110E-04  .827E-05  .662E-05  .496E-05  .331E-05  .248E-05  .165E-05  .124E-05  .827E-06  .551E-06
        ROW   23
                    CONSTANT HEAD FLUX RATES ... LLL/T
 0.        0.        0.        0.        0.        0.        0.        0.        0.        0.
                    ET RATES ... LLL/T
 .166E-04  .124E-04  .993E-05  .745E-05  .497E-05  .373E-05  .248E-05  .186E-05  .124E-05  .828E-06
        ROW   24
                    CONSTANT HEAD FLUX RATES ... LLL/T
 0.        0.        0.        0.        0.        0.        0.        0.        0.        0.
                    ET RATES ... LLL/T
 .249E-04  .186E-04  .149E-04  .112E-04  .746E-05  .559E-05  .373E-05  .280E-05  .186E-05  .124E-05
```

```
      RUN   25
                CONSTANT HEAD FLUX RATES ... LLL/T
0.        0.         0.        0.        0.        0.        0.        0.        0.        0.
                ET RATES ... LLL/T
 .414E-04  .311E-04  .249E-04  .187E-04  .124E-04  .933E-05  .622E-05  .466E-05  .311E-05  .207E-05

      RUN   26
                CONSTANT HEAD FLUX RATES ... LLL/T
0.        0.         0.        0.        0.        0.        0.        0.        0.        0.
                ET RATES ... LLL/T
 .553E-04  .415E-04  .332E-04  .249E-04  .166E-04  .124E-04  .829E-05  .622E-05  .415E-05  .276E-05

      RUN   27
                CONSTANT HEAD FLUX RATES ... LLL/T
0.        0.         0.        0.        0.        0.        0.        0.        0.        0.
                ET RATES ... LLL/T
 .553E-04  .415E-04  .332E-04  .249E-04  .166E-04  .124E-04  .829E-05  .622E-05  .415E-05  .276E-05
```

```
                                        ---------------------------------------------------------
                                        &              TIME STEP NUMBER =        15             &
                                        ---------------------------------------------------------

                                             SIZE OF TIME STEP IN SECONDS=   11951667.86

                                                  TOTAL SIMULATION TIME IN SECONDS=   41561946.66
                                                                          MINUTES=      692699.11
                                                                            HOURS=       11544.99
                                                                             DAYS=         481.04
                                                                            YEARS=           1.32

                                        DURATION OF CURRENT PUMPING PERIOD IN DAYS=        481.04
                                                                            YEARS=           1.32


          CUMULATIVE MASS BALANCE:               L**3                   RATES FOR THIS TIME STEP:              L**3/T
          ------------------------                                      -------------------------
                                                                                           STORAGE =            -.0204
                SOURCES:                                                                  RECHARGE =             .0503
                --------                                                             CONSTANT FLUX =            0.0000
                        STORAGE =          -1366255.09                                     PUMPING =            0.0000
                       RECHARGE =           2089328.20                          EVAPOTRANSPIRATION =            -.0298
                  CONSTANT FLUX =                 0.00                              CONSTANT HEAD:
                  CONSTANT HEAD =                 0.00                                          IN =            0.0000
                        LEAKAGE =                 0.00                                         OUT =            -.0000
                  TOTAL SOURCES =            723073.11                                    LEAKAGE:
                                                                     FROM PREVIOUS PUMPING PERIOD =            0.0000
                DISCHARGES:                                                                  TOTAL =            0.0000
                -----------
             EVAPOTRANSPIRATION =            722143.90                                SUM OF RATES =            -.0000
                  CONSTANT HEAD =               929.21
                QUANTITY PUMPED =                 0.00
                        LEAKAGE =                 0.00
                TOTAL DISCHARGE =            723073.11

              DISCHARGE-SOURCES =                  .00
             PER CENT DIFFERENCE =                 .00


     MAXIMUM HEAD CHANGE FOR EACH ITERATION:
     ---------------------------------------

            .1604      .0002

     MAXIMUM CHANGE IN HEAD FOR THIS TIME STEP =       .465
     ------------------------------------------------------

     TIME STEP :  1  2  3  4  5  6  7  8  9 10 11 12 13 14 15
     ----------

     ITERATIONS:  1  1  1  1  1  1  1  1  2  2  2  1  1  1  1
     ----------
```

```
                                      HEAD MATRIX
                                      -----------

            1   0.00  0.00  0.00  0.00  0.00  0.00  0.00  0.00  0.00  0.00  0.00  0.00

            2   0.00563.00563.00563.00563.00563.00563.00563.00563.00563.00563.00  0.00

            3   0.00564.30564.30564.30564.30564.30564.30564.30564.30564.30564.30  0.00

            4   0.00564.68564.68564.68564.68564.68564.68564.68564.68564.68564.68  0.00

            5   0.00565.01565.01565.01565.01565.01565.01565.01565.01565.01565.01  0.00

            6   0.00565.34565.34565.34565.34565.34565.34565.34565.34565.34565.34  0.00

            7   0.00565.83565.83565.83565.83565.83565.83565.83565.83565.83565.83  0.00

            8   0.00566.07566.07566.07566.07566.07566.07566.07566.07566.07566.07  0.00

            9   0.00566.45566.45566.45566.45566.45566.45566.45566.45566.45566.45  0.00

           10   0.00566.83566.83566.83566.83566.83566.83566.83566.83566.83566.83  0.00

           11   0.00566.96566.96566.96566.96566.96566.96566.96566.96566.96566.96  0.00

           12   0.00567.21567.21567.21567.21567.21567.21567.21567.21567.21567.21  0.00

           13   0.00567.40567.40567.40567.40567.40567.40567.40567.40567.40567.40  0.00

           14   0.00567.78567.78567.78567.78567.78567.78567.78567.78567.78567.78  0.00

           15   0.00568.14568.14568.14568.14568.14568.14568.14568.14568.14568.14  0.00

           16   0.00568.33568.33568.33568.33568.33568.33568.33568.33568.33568.33  0.00

           17   0.00568.46568.46568.46568.46568.46568.46568.46568.46568.46568.46  0.00

           18   0.00568.56568.56568.56568.56568.56568.56568.56568.56568.56568.56  0.00

           19   0.00568.60568.60568.60568.60568.60568.60568.60568.60568.60568.60  0.00

           20   0.00568.62568.62568.62568.62568.62568.62568.62568.62568.62568.62  0.00

           21   0.00568.62568.62568.62568.62568.62568.62568.62568.62568.62568.62  0.00

           22   0.00568.62568.62568.62568.62568.62568.62568.62568.62568.62568.62  0.00

           23   0.00568.62568.62568.62568.62568.62568.62568.62568.62568.62568.62  0.00

           24   0.00568.62568.62568.62568.62568.62568.62568.62568.62568.62568.62  0.00

           25   0.00568.63568.63568.63568.63568.63568.63568.63568.63568.63568.63  0.00

           26   0.00568.63568.63568.63568.63568.63568.63568.63568.63568.63568.63  0.00

           27   0.00568.63568.63568.63568.63568.63568.63568.63568.63568.63568.63  0.00

           28   0.00  0.00  0.00  0.00  0.00  0.00  0.00  0.00  0.00  0.00  0.00  0.00

   ROW    2
            CONSTANT HEAD FLUX RATES ... LLL/T
-.148E-04 -.111E-04 -.888E-05 -.666E-05 -.444E-05 -.333E-05 -.222E-05 -.167E-05 -.111E-05 -.740E-06
            ET RATES ... LLL/T
0.        0.        0.        0.        0.        0.        0.        0.        0.        0.
```

```
        ROW    3
                      CONSTANT HEAD FLUX RATES ... LLL/T
 0.         0.          0.         0.         0.         0.         0.         0.         0.         0.
                      ET RATES ... LLL/T
  .147E-03  .110E-03  .880E-04  .660E-04  .440E-04  .330E-04  .220E-04  .165E-04  .110E-04  .734E-05
        ROW    4
                      CONSTANT HEAD FLUX RATES ... LLL/T
 0.         0.          0.         0.         0.         0.,        0.         0.         0.         0.
                      ET RATES ... LLL/T
  .230E-03  .172E-03  .138E-03  .103E-03  .689E-04  .517E-04  .344E-04  .258E-04  .172E-04  .115E-04
        ROW    5
                      CONSTANT HEAD FLUX RATES ... LLL/T
 0.         0.          0.         0.         0.         0.         0.         0.         0.         0.
                      ET RATES ... LLL/T
  .359E-03  .269E-03  .215E-03  .162E-03  .108E-03  .808E-04  .538E-04  .404E-04  .269E-04  .179E-04
        ROW    6
                      CONSTANT HEAD FLUX RATES ... LLL/T
 0.         0.          0.         0.         0.         0.         0.         0.         0.         0.
                      ET RATES ... LLL/T
  .538E-03  .404E-03  .323E-03  .242E-03  .161E-03  .121E-03  .807E-04  .606E-04  .404E-04  .269E-04
        ROW    7
                      CONSTANT HEAD FLUX RATES ... LLL/T
 0.         0.          0.         0.         0.         0.         0.         0.         0.         0.
                      ET RATES ... LLL/T
  .795E-03  .596E-03  .477E-03  .358E-03  .238E-03  .179E-03  .119E-03  .894E-04  .596E-04  .397E-04
        ROW    8
                      CONSTANT HEAD FLUX RATES ... LLL/T
 0.         0.          0.         0.         0.         0.         0.         0.         0.         0.
                      ET RATES ... LLL/T
  .118E-02  .883E-03  .707E-03  .530E-03  .353E-03  .265E-03  .177E-03  .133E-03  .883E-04  .589E-04
        ROW    9
                      CONSTANT HEAD FLUX RATES ... LLL/T
 0.         0.          0.         0.         0.         0.         0.         0.         0.         0.
                      ET RATES ... LLL/T
  .177E-02  .133E-02  .106E-02  .796E-03  .531E-03  .398E-03  .265E-03  .199E-03  .133E-03  .884E-04
        ROW   10
                      CONSTANT HEAD FLUX RATES ... LLL/T
 0.         0.          0.         0.         0.         0.         0.         0.         0.         0.
                      ET RATES ... LLL/T
  .267E-02  .200E-02  .160E-02  .120E-02  .801E-03  .600E-03  .400E-03  .300E-03  .200E-03  .133E-03
        ROW   11
                      CONSTANT HEAD FLUX RATES ... LLL/T
 0.         0.          0.         0.         0.         0.         0.         0.         0.         0.
                      ET RATES ... LLL/T
  .177E-02  .133E-02  .106E-02  .796E-03  .531E-03  .398E-03  .265E-03  .199E-03  .133E-03  .885E-04
        ROW   12
                      CONSTANT HEAD FLUX RATES ... LLL/T
 0.         0.          0.         0.         0.         0.         0.         0.         0.         0.
                      ET RATES ... LLL/T
  .118E-02  .887E-03  .709E-03  .532E-03  .355E-03  .266E-03  .177E-03  .133E-03  .887E-04  .591E-04
        ROW   13
                      CONSTANT HEAD FLUX RATES ... LLL/T
 0.         0.          0.         0.         0.         0.         0.         0.         0.         0.
                      ET RATES ... LLL/T
  .796E-03  .597E-03  .478E-03  .358E-03  .239E-03  .179E-03  .119E-03  .895E-04  .597E-04  .398E-04
```

```
      ROW   14
                 CONSTANT HEAD FLUX RATES ... LLL/T
 0.        0.        0.        0.        0.        0.        0.        0.        0.        0.
                 ET RATES ... LLL/T
 .540E-03  .405E-03  .324E-03  .243E-03  .162E-03  .122E-03  .810E-04  .608E-04  .405E-04  .270E-04
      ROW   15
                 CONSTANT HEAD FLUX RATES ... LLL/T
 0.        0.        0.        0.        0.        0.        0.        0.        0.        0.
                 ET RATES ... LLL/T
 .361E-03  .271E-03  .217E-03  .162E-03  .108E-03  .812E-04  .542E-04  .406E-04  .271E-04  .181E-04
      ROW   16
                 CONSTANT HEAD FLUX RATES ... LLL/T
 0.        0.        0.        0.        0.        0.        0.        0.        0.        0.
                 ET RATES ... LLL/T
 .231E-03  .174E-03  .139E-03  .104E-03  .694E-04  .521E-04  .347E-04  .260E-04  .174E-04  .116E-04
      ROW   17
                 CONSTANT HEAD FLUX RATES ... LLL/T
 0.        0.        0.        0.        0.        0.        0.        0.        0.        0.
                 ET RATES ... LLL/T
 .154E-03  .116E-03  .926E-04  .695E-04  .463E-04  .347E-04  .232E-04  .174E-04  .116E-04  .772E-05
      ROW   18
                 CONSTANT HEAD FLUX RATES ... LLL/T
 0.        0.        0.        0.        0.        0.        0.        0.        0.        0.
                 ET RATES ... LLL/T
 .101E-03  .758E-04  .606E-04  .455E-04  .303E-04  .227E-04  .152E-04  .114E-04  .758E-05  .505E-05
      ROW   19
                 CONSTANT HEAD FLUX RATES ... LLL/T
 0.        0.        0.        0.        0.        0.        0.        0.        0.        0.
                 ET RATES ... LLL/T
 .751E-04  .563E-04  .450E-04  .338E-04  .225E-04  .169E-04  .113E-04  .844E-05  .563E-05  .375E-05
      ROW   20
                 CONSTANT HEAD FLUX RATES ... LLL/T
 0.        0.        0.        0.        0.        0.        0.        0.        0.        0.
                 ET RATES ... LLL/T
 .454E-04  .341E-04  .273E-04  .204E-04  .136E-04  .102E-04  .682E-05  .511E-05  .341E-05  .227E-05
      ROW   21
                 CONSTANT HEAD FLUX RATES ... LLL/T
 0.        0.        0.        0.        0.        0.        0.        0.        0.        0.
                 ET RATES ... LLL/T
 .304E-04  .228E-04  .182E-04  .137E-04  .912E-05  .684E-05  .456E-05  .342E-05  .228E-05  .152E-05
      ROW   22
                 CONSTANT HEAD FLUX RATES ... LLL/T
 0.        0.        0.        0.        0.        0.        0.        0.        0.        0.
                 ET RATES ... LLL/T
 .203E-04  .152E-04  .122E-04  .914E-05  .609E-05  .457E-05  .305E-05  .229E-05  .152E-05  .102E-05
      ROW   23
                 CONSTANT HEAD FLUX RATES ... LLL/T
 0.        0.        0.        0.        0.        0.        0.        0.        0.        0.
                 ET RATES ... LLL/T
 .305E-04  .229E-04  .183E-04  .137E-04  .916E-05  .687E-05  .458E-05  .343E-05  .229E-05  .153E-05
      ROW   24
                 CONSTANT HEAD FLUX RATES ... LLL/T
 0.        0.        0.        0.        0.        0.        0.        0.        0.        0.
                 ET RATES ... LLL/T
 .459E-04  .344E-04  .275E-04  .206E-04  .138E-04  .103E-04  .688E-05  .516E-05  .344E-05  .229E-05
```

```
       ROW   25
                CONSTANT HEAD FLUX RATES ... LLL/T
 0.        0.        0.        0.        0.        0.        0.        0.        0.        0.
                ET RATES ... LLL/T
 .766E-04  .574E-04  .460E-04  .345E-04  .230E-04  .172E-04  .115E-04  .862E-05  .574E-05  .383E-05

       ROW   26
                CONSTANT HEAD FLUX RATES ... LLL/T
 0.        0.        0.        0.        0.        0.        0.        0.        0.        0.
                ET RATES ... LLL/T
 .102E-03  .767E-04  .614E-04  .460E-04  .307E-04  .230E-04  .153E-04  .115E-04  .767E-05  .511E-05

       ROW   27
                CONSTANT HEAD FLUX RATES ... LLL/T
 0.        0.        0.        0.        0.        0.        0.        0.        0.        0.
                ET RATES ... LLL/T
 .102E-03  .768E-04  .614E-04  .461E-04  .307E-04  .230E-04  .154E-04  .115E-04  .768E-05  .512E-05
```

```
                                    ---------------------------------------------------------
                                    *               TIME STEP NUMBER =        20            *
                                    ---------------------------------------------------------

                                         SIZE OF TIME STEP IN SECONDS=   64278938.15

                                              TOTAL SIMULATION TIME IN SECONDS=  224707392.69
                                                                      MINUTES=    3745123.21
                                                                        HOURS=      62418.72
                                                                         DAYS=       2600.78
                                                                        YEARS=          7.13

                                    DURATION OF CURRENT PUMPING PERIOD IN DAYS=       2600.78
                                                                        YEARS=          7.13


              CUMULATIVE MASS BALANCE:              L**3                    RATES FOR THIS TIME STEP:                L**3/T
              ------------------------                                      -------------------------

                   SOURCES:                                                                 STORAGE =              -.0007
                   --------                                                                RECHARGE =               .0503
                             STORAGE =           -2063182.62                          CONSTANT FLUX =              0.0000
                            RECHARGE =           11296090.07                                PUMPING =              0.0000
                       CONSTANT FLUX =                  0.00                     EVAPOTRANSPIRATION =              -.0496
                       CONSTANT HEAD =                  0.00                         CONSTANT HEAD:
                             LEAKAGE =                  0.00                                     IN =              0.0000
                       TOTAL SOURCES =            9232907.45                                    OUT =              -.0001
                                                                                           LEAKAGE:
                   DISCHARGES:                                          FROM PREVIOUS PUMPING PERIOD =              0.0000
                   -----------                                                                TOTAL =              0.0000
                  EVAPOTRANSPIRATION =            9222487.45
                       CONSTANT HEAD =              10420.00                           SUM OF RATES =              -.0000
                     QUANTITY PUMPED =                  0.00
                             LEAKAGE =                  0.00
                     TOTAL DISCHARGE =            9232907.45

                   DISCHARGE-SOURCES =                   .00
                  PER CENT DIFFERENCE =                  .00


         MAXIMUM HEAD CHANGE FOR EACH ITERATION:
         ---------------------------------------

               .0350      .0001

         MAXIMUM CHANGE IN HEAD FOR THIS TIME STEP =       .084
         --------------------------------------------------------

         TIME STEP :  1  2  3  4  5  6  7  8  9 10 11 12 13 14 15 16 17 18 19 20
         ----------

         ITERATIONS:  1  1  1  1  1  1  1  1  2  2  2  1  1  1  1  1  1  1  1  1
         ----------
```

```
                                  HEAD MATRIX
                                  -----------

           1    0.00  0.00  0.00  0.00  0.00  0.00  0.00  0.00  0.00  0.00  0.00  0.00
           2    0.00563.00563.00563.00563.00563.00563.00563.00563.00563.00563.00  0.00
           3    0.00564.88564.88564.88564.88564.88564.88564.88564.88564.88564.88  0.00
           4    0.00565.50565.50565.50565.50565.50565.50565.50565.50565.50565.50  0.00
           5    0.00566.02566.02566.02566.02566.02566.02566.02566.02566.02566.02  0.00
           6    0.00566.52566.52566.52566.52566.52566.52566.52566.52566.52566.52  0.00
           7    0.00567.02567.02567.02567.02567.02567.02567.02567.02567.02567.02  0.00
           8    0.00567.41567.41567.41567.41567.41567.41567.41567.41567.41567.41  0.00
           9    0.00567.72567.72567.72567.72567.72567.72567.72567.72567.72567.72  0.00
          10    0.00568.02568.02568.02568.02568.02568.02568.02568.02568.02568.02  0.00
          11    0.00568.22568.22568.22568.22568.22568.22568.22568.22568.22568.22  0.00
          12    0.00568.32568.32568.32568.32568.32568.32568.32568.32568.32568.32  0.00
          13    0.00568.62568.62568.62568.62568.62568.62568.62568.62568.62568.62  0.00
          14    0.00568.93568.93568.93568.93568.93568.93568.93568.93568.93568.93  0.00
          15    0.00569.23569.23569.23569.23569.23569.23569.23569.23569.23569.23  0.00
          16    0.00569.52569.52569.52569.52569.52569.52569.52569.52569.52569.52  0.00
          17    0.00569.73569.73569.73569.73569.73569.73569.73569.73569.73569.73  0.00
          18    0.00569.87569.87569.87569.87569.87569.87569.87569.87569.87569.87  0.00
          19    0.00569.94569.94569.94569.94569.94569.94569.94569.94569.94569.94  0.00
          20    0.00569.97569.97569.97569.97569.97569.97569.97569.97569.97569.97  0.00
          21    0.00569.98569.98569.98569.98569.98569.98569.98569.98569.98569.98  0.00
          22    0.00569.99569.99569.99569.99569.99569.99569.99569.99569.99569.99  0.00
          23    0.00569.99569.99569.99569.99569.99569.99569.99569.99569.99569.99  0.00
          24    0.00570.00570.00570.00570.00570.00570.00570.00570.00570.00570.00  0.00
          25    0.00570.00570.00570.00570.00570.00570.00570.00570.00570.00570.00  0.00
          26    0.00570.01570.01570.01570.01570.01570.01570.01570.01570.01570.01  0.00
          27    0.00570.01570.01570.01570.01570.01570.01570.01570.01570.01570.01  0.00
          26    0.00  0.00  0.00  0.00  0.00  0.00  0.00  0.00  0.00  0.00  0.00  0.00

$$$$$STEADY STATE AT TIME STEP  24$$$$$

      ROW    2
              CONSTANT HEAD FLUX RATES ..., LLL/T
```

```
-.150E-04 -.112E-04 -.898E-05 -.674E-05 -.449E-05 -.337E-05 -.225E-05 -.168E-05 -.112E-05 -.749E-06
                    ET RATES ... LLL/T
 0.        0.        0.        0.        0.        0.        0.        0.        0.        0.

       ROW    3
                    CONSTANT HEAD FLUX RATES ... LLL/T
 0.        0.        0.        0.        0.        0.        0.        0.        0.        0.
                    ET RATES ... LLL/T
 .148E-03  .111E-03  .886E-04  .664E-04  .443E-04  .332E-04  .221E-04  .166E-04  .111E-04  .738E-05

       ROW    4
                    CONSTANT HEAD FLUX RATES ... LLL/T
 0.        0.        0.        0.        0.        0.        0.        0.        0.        0.
                    ET RATES ... LLL/T
 .232E-03  .174E-03  .139E-03  .104E-03  .695E-04  .521E-04  .347E-04  .261E-04  .174E-04  .116E-04

       ROW    5
                    CONSTANT HEAD FLUX RATES ... LLL/T
 0.        0.        0.        0.        0.        0.        0.        0.        0.        0.
                    ET RATES ... LLL/T
 .363E-03  .272E-03  .218E-03  .163E-03  .109E-03  .816E-04  .544E-04  .408E-04  .272E-04  .181E-04

       ROW    6
                    CONSTANT HEAD FLUX RATES ... LLL/T
 0.        0.        0.        0.        0.        0.        0.        0.        0.        0.
                    ET RATES ... LLL/T
 .545E-03  .409E-03  .327E-03  .245E-03  .164E-03  .123E-03  .818E-04  .613E-04  .409E-04  .273E-04

       ROW    7
                    CONSTANT HEAD FLUX RATES ... LLL/T
 0.        0.        0.        0.        0.        0.        0.        0.        0.        0.
                    ET RATES ... LLL/T
 .805E-03  .604E-03  .483E-03  .362E-03  .242E-03  .181E-03  .121E-03  .906E-04  .604E-04  .403E-04

       ROW    8
                    CONSTANT HEAD FLUX RATES ... LLL/T
 0.        0.        0.        0.        0.        0.        0.        0.        0.        0.
                    ET RATES ... LLL/T
 .120E-02  .897E-03  .717E-03  .538E-03  .359E-03  .269E-03  .179E-03  .134E-03  .897E-04  .598E-04

       ROW    9
                    CONSTANT HEAD FLUX RATES ... LLL/T
 0.        0.        0.        0.        0.        0.        0.        0.        0.        0.
                    ET RATES ... LLL/T
 .179E-02  .135E-02  .108E-02  .807E-03  .538E-03  .404E-03  .269E-03  .202E-03  .135E-03  .897E-04

       ROW   10
                    CONSTANT HEAD FLUX RATES ... LLL/T
 0.        0.        0.        0.        0.        0.        0.        0.        0.        0.
                    ET RATES ... LLL/T
 .270E-02  .203E-02  .162E-02  .122E-02  .811E-03  .608E-03  .406E-03  .304E-03  .203E-03  .135E-03

       ROW   11
                    CONSTANT HEAD FLUX RATES ... LLL/T
 0.        0.        0.        0.        0.        0.        0.        0.        0.        0.
                    ET RATES ... LLL/T
 .179E-02  .135E-02  .108E-02  .807E-03  .538E-03  .404E-03  .269E-03  .202E-03  .135E-03  .897E-04

       ROW   12
                    CONSTANT HEAD FLUX RATES ... LLL/T
 0.        0.        0.        0.        0.        0.        0.        0.        0.        0.
                    ET RATES ... LLL/T
 .120E-02  .898E-03  .718E-03  .539E-03  .359E-03  .269E-03  .180E-03  .135E-03  .898E-04  .598E-04

       ROW   13
                    CONSTANT HEAD FLUX RATES ... LLL/T
 0.       0.       0.       0.       0.       0.       0.       0.       0.       0.
                 ET RATES ... LLL/T
  .807E-03  .605E-03  .484E-03  .363E-03  .242E-03  .182E-03  .121E-03  .908E-04  .605E-04  .403E-04

      ROW   14
                 CONSTANT HEAD FLUX RATES ... LLL/T
 0.       0.       0.       0.       0.       0.       0.       0.       0.       0.
                 ET RATES ... LLL/T
  .547E-03  .410E-03  .328E-03  .246E-03  .164E-03  .123E-03  .821E-04  .615E-04  .410E-04  .274E-04

      ROW   15
                 CONSTANT HEAD FLUX RATES ... LLL/T
 0.       0.       0.       0.       0.       0.       0.       0.       0.       0.
                 ET RATES ... LLL/T
  .366E-03  .274E-03  .219E-03  .164E-03  .110E-03  .822E-04  .548E-04  .411E-04  .274E-04  .183E-04

      ROW   16
                 CONSTANT HEAD FLUX RATES ... LLL/T
 0.       0.       0.       0.       0.       0.       0.       0.       0.       0.
                 ET RATES ... LLL/T
  .234E-03  .176E-03  .141E-03  .106E-03  .703E-04  .528E-04  .352E-04  .264E-04  .176E-04  .117E-04

      ROW   17
                 CONSTANT HEAD FLUX RATES ... LLL/T
 0.       0.       0.       0.       0.       0.       0.       0.       0.       0.
                 ET RATES ... LLL/T
  .156E-03  .117E-03  .939E-04  .704E-04  .469E-04  .352E-04  .235E-04  .176E-04  .117E-04  .782E-05

      ROW   18
                 CONSTANT HEAD FLUX RATES ... LLL/T
 0.       0.       0.       0.       0.       0.       0.       0.       0.       0.
                 ET RATES ... LLL/T
  .102E-03  .769E-04  .615E-04  .461E-04  .307E-04  .231E-04  .154E-04  .115E-04  .769E-05  .512E-05

      ROW   19
                 CONSTANT HEAD FLUX RATES ... LLL/T
 0.       0.       0.       0.       0.       0.       0.       0.       0.       0.
                 ET RATES ... LLL/T
  .762E-04  .571E-04  .457E-04  .343E-04  .229E-04  .171E-04  .114E-04  .857E-05  .571E-05  .381E-05

      ROW   20
                 CONSTANT HEAD FLUX RATES ... LLL/T
 0.       0.       0.       0.       0.       0.       0.       0.       0.       0.
                 ET RATES ... LLL/T
  .461E-04  .346E-04  .277E-04  .208E-04  .138E-04  .104E-04  .692E-05  .519E-05  .346E-05  .231E-05

      ROW   21
                 CONSTANT HEAD FLUX RATES ... LLL/T
 0.       0.       0.       0.       0.       0.       0.       0.       0.       0.
                 ET RATES ... LLL/T
  .309E-04  .231E-04  .185E-04  .139E-04  .926E-05  .694E-05  .463E-05  .347E-05  .231E-05  .154E-05

      ROW   22
                 CONSTANT HEAD FLUX RATES ... LLL/T
 0.       0.       0.       0.       0.       0.       0.       0.       0.       0.
                 ET RATES ... LLL/T
  .206E-04  .155E-04  .124E-04  .928E-05  .619E-05  .464E-05  .309E-05  .232E-05  .155E-05  .103E-05

      ROW   23
                 CONSTANT HEAD FLUX RATES ... LLL/T
 0.       0.       0.       0.       0.       0.       0.       0.       0.       0.
                 ET RATES ... LLL/T
  .310E-04  .232E-04  .186E-04  .139E-04  .929E-05  .697E-05  .465E-05  .349E-05  .232E-05  .155E-05

      ROW   24
                 CONSTANT HEAD FLUX RATES ... LLL/T
 0.        0.        0.        0.        0.        0.        0.        0.        0.        0.
                ET RATES ... LLL/T
 .466E-04  .349E-04  .279E-04  .210E-04  .140E-04  .105E-04  .698E-05  .524E-05  .349E-05  .233E-05

      ROW   25
                CONSTANT HEAD FLUX RATES ... LLL/T
 0.        0.        0.        0.        0.        0.        0.        0.        0.        0.
                ET RATES ... LLL/T
 .778E-04  .583E-04  .467E-04  .350E-04  .233E-04  .175E-04  .117E-04  .875E-05  .583E-05  .389E-05

      ROW   26
                CONSTANT HEAD FLUX RATES ... LLL/T
 0.        0.        0.        0.        0.        0.        0.        0.        0.        0.
                ET RATES ... LLL/T
 .104E-03  .779E-04  .623E-04  .467E-04  .312E-04  .234E-04  .156E-04  .117E-04  .779E-05  .519E-05

      ROW   27
                CONSTANT HEAD FLUX RATES ... LLL/T
 0.        0.        0.        0.        0.        0.        0.        0.        0.        0.
                ET RATES ... LLL/T
 .104E-03  .779E-04  .623E-04  .468E-04  .312E-04  .234E-04  .156E-04  .117E-04  .779E-05  .520E-05
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                          ----------------------------------
                          *         TIME STEP NUMBER =    24        *
                          ----------------------------------

                             SIZE OF TIME STEP IN SECONDS=  246933968.81

                                TOTAL SIMULATION TIME IN SECONDS=  864000000.00
                                                        MINUTES=   14400000.00
                                                          HOURS=     240000.00
                                                           DAYS=      10000.00
                                                          YEARS=         27.40


                          DURATION OF CURRENT PUMPING PERIOD IN DAYS=      10000.00
                                                          YEARS=         27.40


      CUMULATIVE MASS BALANCE:          L**3                RATES FOR THIS TIME STEP:            L**3/T
      ------------------------                              -------------------------

            SOURCES:                                                      STORAGE =           -.0000
            --------                                                     RECHARGE =            .0503
                  STORAGE =         -2086551.71                      CONSTANT FLUX =           0.0000
                 RECHARGE =         43433470.08                            PUMPING =           0.0000
             CONSTANT FLUX =              0.00                 EVAPOTRANSPIRATION =           -.0502
             CONSTANT HEAD =              0.00                     CONSTANT HEAD:
                  LEAKAGE =              0.00                                  IN =           0.0000
            TOTAL SOURCES =         41346918.37                                OUT =           -.0001
                                                                          LEAKAGE:
            DISCHARGES:                           FROM PREVIOUS PUMPING PERIOD =           0.0000
            -----------                                                     TOTAL =           0.0000
        EVAPOTRANSPIRATION =         41300988.47
             CONSTANT HEAD =            45929.90                      SUM OF RATES =           -.0000
           QUANTITY PUMPED =              0.00
                  LEAKAGE =              0.00
          TOTAL DISCHARGE =         41346918.37

        DISCHARGE-SOURCES =                 .00
       PER CENT DIFFERENCE =                 .00


MAXIMUM HEAD CHANGE FOR EACH ITERATION:
---------------------------------------

    .0012      .0000

MAXIMUM CHANGE IN HEAD FOR THIS TIME STEP =       .000
----------------------------------------------------

TIME STEP :  1  2  3  4  5  6  7  8  9 10 11 12 13 14 15 16 17 18 19 20 21 22 23 24
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ITERATIONS:  1  1  1  1  1  1  1  1  2  2  2  1  1  1  1  1  1  1  1  1  1  1  1  1
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                                   HEAD MATRIX
                                   -----------

 1    0.00  0.00  0.00  0.00  0.00  0.00  0.00  0.00  0.00  0.00  0.00   0.00
 2    0.00563.00563.00563.00563.00563.00563.00563.00563.00563.00563.00   0.00
 3    0.00564.89564.89564.89564.89564.89564.89564.89564.89564.89564.89   0.00
 4    0.00565.53565.53565.53565.53565.53565.53565.53565.53565.53565.53   0.00
 5    0.00566.05566.05566.05566.05566.05566.05566.05566.05566.05566.05   0.00
 6    0.00566.55566.55566.55566.55566.55566.55566.55566.55566.55566.55   0.00
 7    0.00567.06567.06567.06567.06567.06567.06567.06567.06567.06567.06   0.00
 8    0.00567.46567.46567.46567.46567.46567.46567.46567.46567.46567.46   0.00
 9    0.00567.76567.76567.76567.76567.76567.76567.76567.76567.76567.76   0.00
10    0.00568.06568.06568.06568.06568.06568.06568.06568.06568.06568.06   0.00
11    0.00568.26568.26568.26568.26568.26568.26568.26568.26568.26568.26   0.00
12    0.00568.36568.36568.36568.36568.36568.36568.36568.36568.36568.36   0.00
13    0.00568.66568.66568.66568.66568.66568.66568.66568.66568.66568.66   0.00
14    0.00568.96568.96568.96568.96568.96568.96568.96568.96568.96568.96   0.00
15    0.00569.27569.27569.27569.27569.27569.27569.27569.27569.27569.27   0.00
16    0.00569.56569.56569.56569.56569.56569.56569.56569.56569.56569.56   0.00
17    0.00569.77569.77569.77569.77569.77569.77569.77569.77569.77569.77   0.00
18    0.00569.91569.91569.91569.91569.91569.91569.91569.91569.91569.91   0.00
19    0.00569.99569.99569.99569.99569.99569.99569.99569.99569.99569.99   0.00
20    0.00570.01570.01570.01570.01570.01570.01570.01570.01570.01570.01   0.00
21    0.00570.03570.03570.03570.03570.03570.03570.03570.03570.03570.03   0.00
22    0.00570.03570.03570.03570.03570.03570.03570.03570.03570.03570.03   0.00
23    0.00570.04570.04570.04570.04570.04570.04570.04570.04570.04570.04   0.00
24    0.00570.04570.04570.04570.04570.04570.04570.04570.04570.04570.04   0.00
25    0.00570.05570.05570.05570.05570.05570.05570.05570.05570.05570.05   0.00
26    0.00570.05570.05570.05570.05570.05570.05570.05570.05570.05570.05   0.00
27    0.00570.06570.06570.06570.06570.06570.06570.06570.06570.06570.06   0.00
28    0.00  0.00  0.00  0.00  0.00  0.00  0.00  0.00  0.00  0.00  0.00   0.00
```